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Resistance Analysis of Axially Loaded Drilled Shafts Socketed in Shale

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Resistance Analysis of Axially Loaded Drilled Shafts Socketed in Shale

by

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Thesis

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Abstract

Resistance Analysis of Axially Loaded Drilled Shafts Socketed in Shale

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The University of Texas at Austin, 2013

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An investigation into the load-settlement behavior of two drilled shafts, founded in shale, is presented. The motivation for this research is to advance the understanding on how drilled shafts react under loading in stiff clays and shales. The objectives of the study are to measure the strengths within the subsurface material at the test site, estimate the unit side shear and unit end bearing of the shale-shaft interaction by running two axial load tests, and compare the results to the current design methods that are used to predict the axial capacity of drilled shafts.

A comprehensive field investigation, performed by Fugro Consultants, provided strength profiles of the subsurface material at the test site. Through the cooperation of the Texas Department of Transportation (TxDOT), the Association of Drilled Shaft Contractors, and McKinney Drilling Company, two drilled shafts were installed at a highway construction site in Austin, Texas. The load tests were performed by Loadtest, Inc.; using the patented Osterberg-Cell™ loading technique to axially displace the shafts.

Ensoft, Inc. installed strain gauges at multiple levels within the shafts, making it possible to analyze the shaft mobilization during loading.

Ultimate end bearing values of about 100- and 120-ksf were measured for Test Shafts #1 and #2, respectively. The current methods for estimating unit end bearing, developed by TxDOT and the Federal Highway Administration, provide fairly accurate predictions when compared to the measured information. The ultimate side resistance obtained near the O-Cell™ in each test was about 20-ksf, however, the measured ultimate side resistance steadily decreased nearing the tip of the shaft. For the zones where the side resistance was believed to be fully mobilized, the TxDOT design method accurately predicts the side resistance. A limited amount of information is currently available for load tests performed in soils with TCP values harder than 2-in per 100 blows. Additional load test information should allow for a stronger correlation between TCP tests and unit resistances for very hard clay-shales, as well as, allowing for further evaluation of the shale-shaft interaction near the shaft tip. The results presented herein demonstrate the effectiveness of the current design methods for drilled shafts and the non-uniformity of side resistance within one- to two-diameters of the shaft tip.

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Chapter 1: Introduction

1.1 MOTIVATION

Drilled shafts, socketed in shale, are often used to support bridges and buildings in Texas. The design of rock-socketed drilled shafts founded in shales require a vast amount of engineering judgment to be made, namely in properly assessing the strength of the shale. The evaluation of the shale strength can be challenging at times, whether it is determined from compressive strength tests or Texas Cone Penetration (TCP) tests. Acquiring adequate samples remains a difficult task due to the natural cracks and fissures existing in the shale strata. These anomalies cause erratic compressive strength test results, preventing an accurate estimation of the in-situ strength of the shale layers. The TCP tests provide an in-situ alternative of estimating the strength of soils, using pre-established correlations to predict shaft capacities. Although the method is frequently used for the design of drilled shafts in cohesive soils, little information exists providing the accuracy of the design curves to soils harder than 2-in per 100 blows (values obtained from TCP testing).

1.2 OBJECTIVES

The goals of this study are to: (1) measure the compressive strengths and TCP values within the shale of which the test shafts will be socketed, (2) estimate the unit side shear and unit end bearing of the shale-shaft interaction by running two load tests, and (3) evaluate the accuracy of current design methods that are used to predict the axial capacity of drilled shafts in shales.

1.3 METHODOLOGY

The study described herein is an effort to further characterize the loading performance of drilled shafts founded shales. The laboratory and in-situ strengths of the shale will be measured using current strength testing techniques. The shafts, equipped with strain gauges at multiple levels, are then placed in the shale and load tested. After loading, the applied loads and subsequent strains throughout the shaft are used to estimate the developed unit side shear and end bearing as the shaft displaced. This information will allow the research team to further understand the performance of drilled shafts under loading in shales. Completing these objectives will allow future design of drilled shafts in similar soils to be more structurally reliable and, in turn, cost efficient.

1.4 THESIS ORGANIZATION

This thesis is organized into 10 chapters. Chapter 2 discusses conventional and O-Cell™ load testing, along with a literature review of results and methods developed by prior research studies for load tests in clay-shales. Chapter 3 covers two current methods being used to design drilled shafts in shales. The TxDOT design method uses empirical relationships between the TCP test results and corresponding values of unit side shear and unit end bearing. The FHWA procedure predicts the capacity of the shaft by the use of compressive strength values available from unconfined compression tests. Each method includes an example calculations for a generic shaft socketed into shale.

Chapter 4 discusses the sampling and strength testing procedures used to profile the subsurface material in this study, as well as, the field investigation performed at the site of the load tests. Two borings were performed at the site; Boring B-1 consisting of continuous rock coring for the entire boring and Boring B-1A consisting of TCP tests run the entire length of the borehole. Each boring was proceeded to a depth of 90-ft, 10-ft deeper than the tip of the shafts, to obtain a full profile of the subsurface material that interacts with the test shafts.

Chapter 5 discusses the locations of the test shafts in relation to the boreholes, along with the determination of the O-Cell™ placement within the drilled shaft and the loading procedure. Chapter 6 explains general O-Cell™ results and diagrams, strain gauge information, and methods of unit resistance calculations.

Chapter 7 describes the construction process and the final as-built information for each test shaft. Also, the concrete strength testing and SoniCaliper data is discussed. The shafts were installed at different times, allowing the results of Test Shaft #1 to influence the placement of the O-Cell™ and strain gauges in Test Shaft #2.

The general results from the two load tests are presented in Chapter 8, such as load-displacement, equivalent top-down loading, and creep limit estimations. In Chapter 9, the loading distributions, along with the measured unit side shear and end bearing of the shafts are analyzed and compared to current and previous design methods of drilled shafts socketed in shale.

Chapter 2: Load Testing and Literature Review

This chapter discusses prior attempts at developing accurate models to predict the axial capacity of drilled shafts placed in shales. Aurora and Reese (1976) performed four load tests at two locations in Texas, with the goal of developing a relationship to predict the axial capacity for drilled shafts socketed in clay-shales. O'Neill and Reese (1999) developed a method to relate the unconfined compressive strength to the axial capacity of drilled shafts socketed in weak clay-shales. Also discussed is the analysis performed by Nam and Vipulanandan (2010); involving three Osterberg-Cell™ (O-Cell™) load tests to further evaluate the correlation between TCP testing and the maximum side shear and end bearing of a drilled shaft socketed in hard to very hard cohesive materials.

2.1 Conventional Load Testing

Conventional load testing involves applying a static load to the top of a pile/shaft and using a reaction system to push down on the pile. A general set-up for a conventional load testing system is presented in Figure 2.1. The hydraulic jack is pressurized in sequential loading increments, with each step being held for a planned duration. The movement of the top of the pile is measured using dial gauges connected to a free-standing reference beam. The pile is loaded incrementally, until the pre-planned failure criterion has been met (usually displacement of 5% of the pile diameter or pile plunging). Conventional load testing mimics an actual structural dead load, making the procedure beneficial in the eyes of a design engineer. Unappealing factors, such as cost, required space, extreme loads, and time, make conventional load testing a hindrance on many projects.

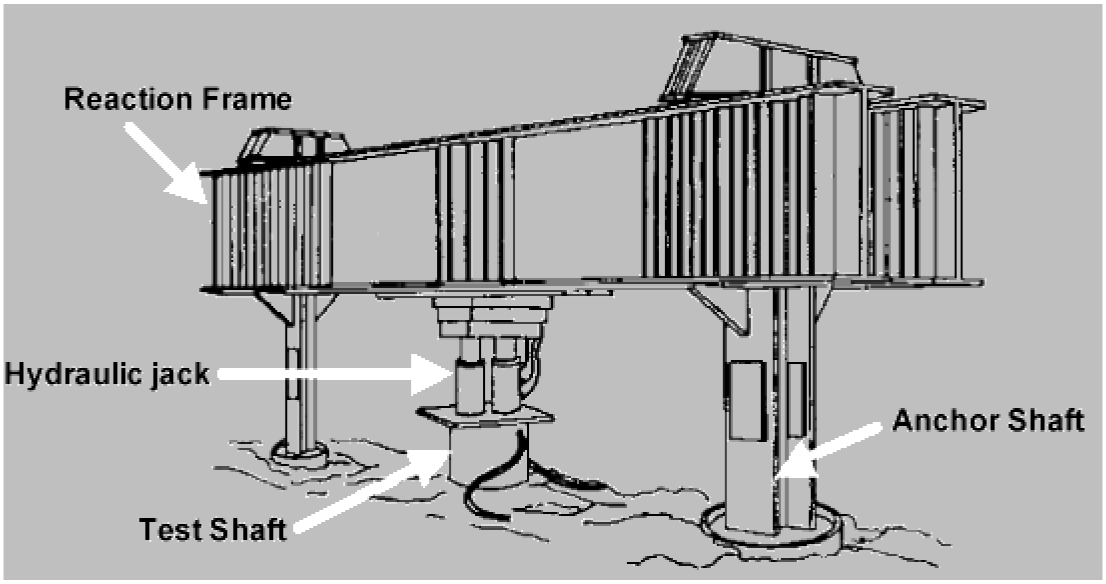


Figure 2.1: Top-Down Load Testing Schematic (Ardiansyah)

2.2 O-CELL™ LOAD TESTING

The O-Cell™, invented by Dr. Jorj O. Osterberg, is a hydraulically powered, sacrificial load cell that is installed within the test shaft. Hydraulic cables run up the pile, along the carrying frame, allowing the field crew to apply pressure and subsequently load the pile. Figure 2.2 is very similar to the setup used in this study, with exception to the rebar cage supporting the shaft. The principle advantage of the O-Cell™ setup is there are no requirements for a reaction system. The reaction occurs within the shaft, whereas the O-Cell™ begins to expand from applied hydraulic pressure as shown in Figure 2.3. The expansion causes load to be applied on each shaft (upper and lower), using the adjacent shaft as the reaction system. This benefit saves time, money, and space for a project. The difference in the magnitude of resistance needed to mobilize the 80-ft drilled shafts in this study is another major advantage for running an O-Cell™ load test. Using the conventional, top-down load test method, much larger loads would be required to mobilize the entire shaft, along with a very large reaction frame (including reaction beams and adjacent reaction piles).

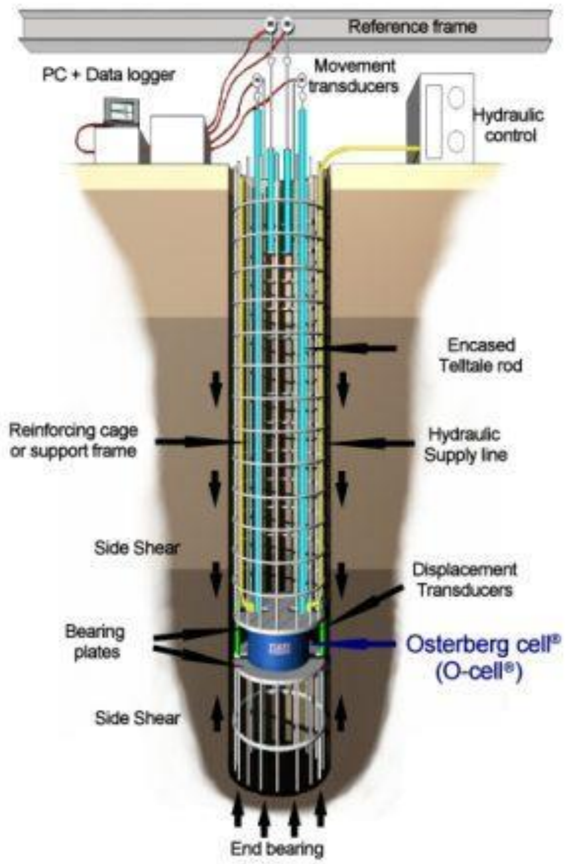


Figure 2.2: General O-Cell™ Setup (Note: A Rebar Cage Was Not Used In This Study) (Loadtest)

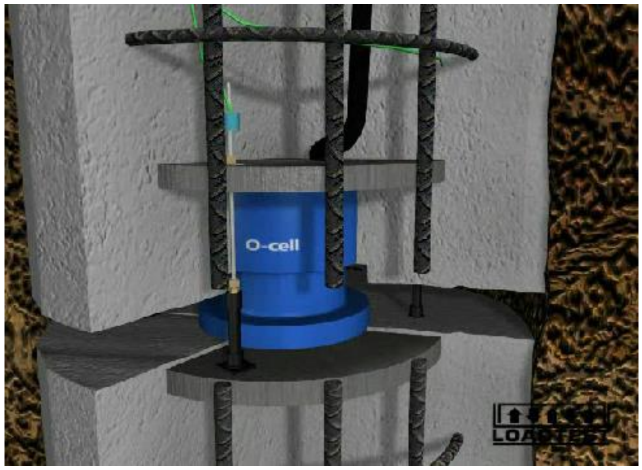
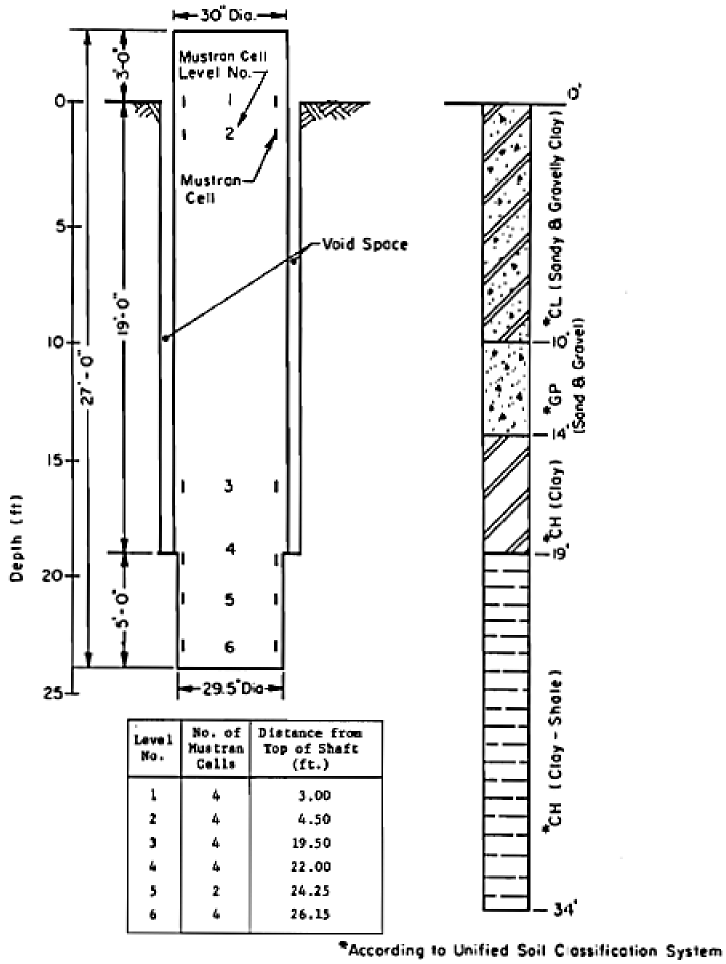


Figure 2.3: Expansion of the O-Cell™ Caused by Increasing Hydraulic Pressure (Loadtest)

2.3 AURORA AND REESE

Attempting to develop a method of designing drilled shafts placed in clay-shales, Aurora and Reese (1976) performed axial load tests at two locations in Texas. A total of four drilled shafts were load tested; three in Austin, Texas (MT1, MT2, and MT3; the area is commonly referred to as Montopolis) and one in Dallas, Texas (DT1). The four shafts investigated in the study were socketed about 5-ft into the shale strata. The sides of the shafts were resisted primarily by clay, with intermittent sand and gravel, as shown in the schematic diagrams for shaft MT3 (Figure 2.4). The tip load versus tip settlement plots of the four test shafts are shown in Figure 2.5. The load transfer curves were presented within the shale for shaft MT3 and are shown in Figure 2.6. The load transfer curves were not presented within the shale for shafts MT1 and MT2 due to erratic behavior during testing.



Level No.	No. of Mustran Cells	Distance from Top of Shaft (ft.)
1	4	3.00
2	4	4.50
3	4	19.50
4	4	22.00
5	2	24.25
6	4	26.15

*According to Unified Soil Classification System

Figure 2.4: Drilled Shaft Schematic of MT3; Located in Austin (Montopolis), Texas (Aurora and Reese, 1976)

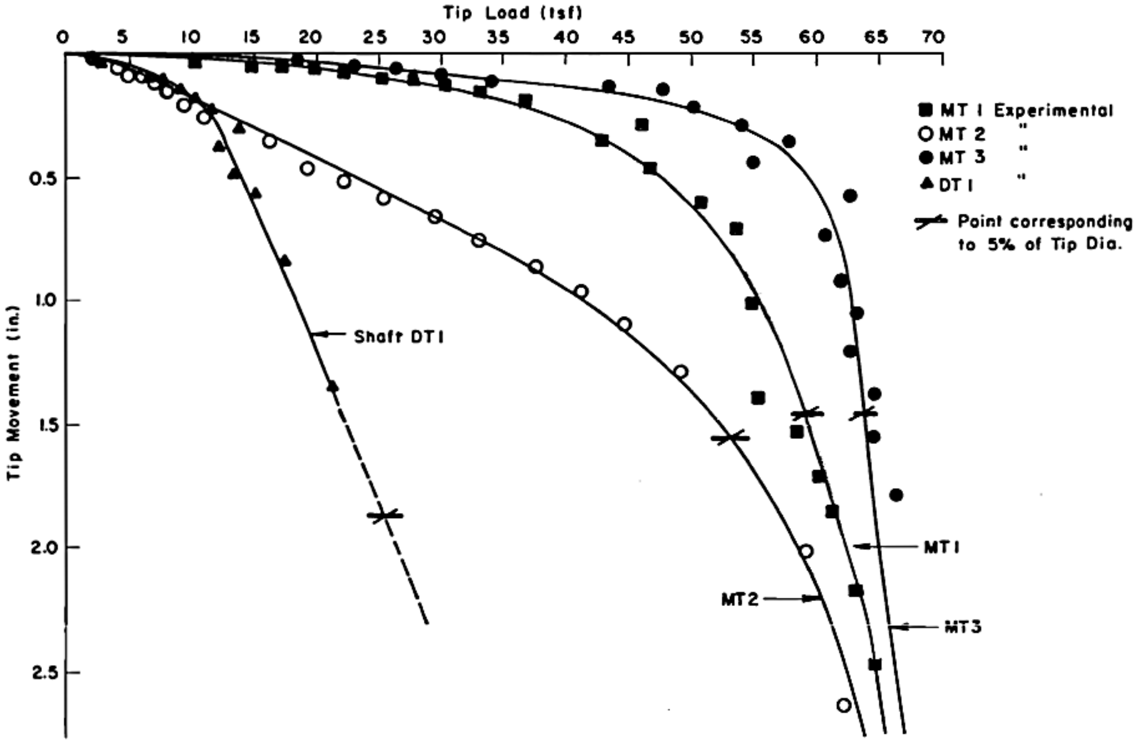


Figure 2.5: Tip Load vs. Tip Movement for Each Test Shaft Performed by Aurora and Reese (1976)

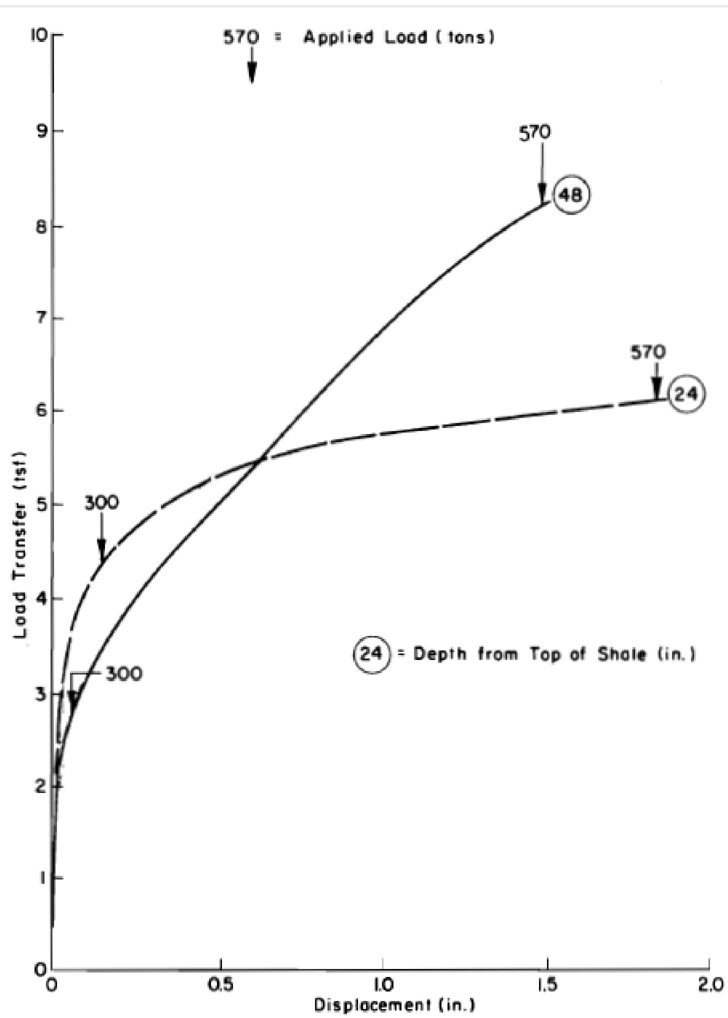


Figure 2.6: Load Transfer Curves for Shaft MT3

Using information gained from the load test program, relationships between the shear strength of the shale and the axial capacity of the drilled shaft were developed. The ultimate unit base resistance (q) was defined as:

$$q = c_q \, N_c \qquad \text{Eq. 2.1}$$

where c_q is the shear strength, in tsf, of the clay shale obtained from a triaxial test and N_c is the bearing capacity factor (N_c= 7.0 for shafts constructed via slurry displacement method and N_c= 8.0 for shafts constructed via the casing or dry method). The total base resistance (Q_B) is calculated as the unit base resistance multiplied by the cross-sectional area of the shaft base. The unit side resistance (f_s) is estimated using the following relationship:

$$f_s = \alpha \, c_q \qquad \text{Eq. 2.2}$$

where, α is the shear strength reduction factor (α = 0.5 for shafts constructed via slurry displacement or casing method and α = 0.75 for shafts constructed via the dry method) and c_q is the same as defined above. The total side resistance (Q_S) is calculated by multiplying the unit side resistance by the surface area of the shaft perimeter. The total axial capacity (Q_T) of the shaft is then calculated as the sum of the total base resistance and total side resistance. The total allowable load (Q_A) was suggested as follows:

$$Q_A = \frac{Q_B}{2} + Q_S \qquad \text{Eq. 2.3}$$

Table 2.1 compares the experimental results from the four load tests with the calculated capacities determined from the developed method. In comparison of the experimental and computed capacities, the design method developed by Aurora and Reese is somewhat conservative.

Table 2.1: Comparative Ultimate Axial Capacities in Clay-Shales: Experimental and Computed. (Aurora and Reese, 1976)

Shaft No.	Construction Method	Experimental Axial Capacity (tons)	Computed Axial Capacity (tons)
MT 1	Casing	517	396
MT 2	Slurry	521	404
MT 3	Dry	570	485
DT 1	Casing	290	237

2.4 O'NEILL AND REESE

During the development of the updated FHWA manual, *Drilled Shafts: Construction Procedures and Design Methods (O'Neill, 1999)*, O'Neill and Reese defined a new sub-group for cohesive materials that are difficult to sample and test using current drilling techniques. This design method is included in the newest version of the FHWA drilled shaft manual (Brown et al., 2010), used as part of the Load and Resistance Factor Design (LRFD) procedures. These weak clay-shales can be referred to as a "cohesive intermediate geo-material (IGM)," a term coined by O'Neill et al. (1996). Expanding on previous studies of drilled shafts founded in shales, O'Neill and Reese (1999) developed a method to predict the side resistance of cohesive IGMs, similar to using the α-method for cohesive materials. The nominal unit side resistance (f_{SN}) is calculated using the following equation:

$$f_{SN} = \alpha \, \varphi \, q_u \qquad \text{Eq. 2.4}$$

where α is the empirical factor given in Figure 2.7, φ is the correction factor to account for the degree of jointing (Table 2.2), and q_u is the compressive strength of the cohesive IGM. The FHWA procedure recommends that a resistance factor of 0.6 is applied to f_{SN}.

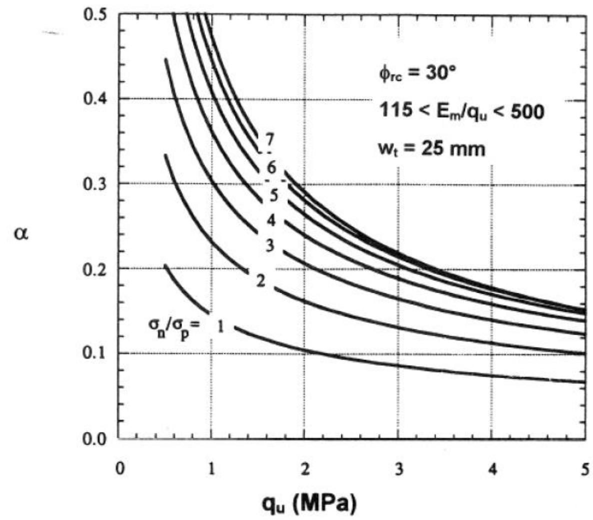


Figure 2.7: Relationship of Compressive Strength to α for Cohesive IGM (O'Neill, 1996) (25 mm = 1 inch; 1 MPa = 10.5 tsf)

Table 2.2: Side Resistance Reduction Factor (O'Neill, 1999)

RQD (%)	**Joint Modification Factor, φ**	
	Closed Joints	Open of Gouge-Filled Joints
100	1.00	0.85
70	0.85	0.55
50	0.60	0.55
30	0.50	0.50
20	0.45	0.45

In selecting the appropriate alpha value, the relationship of σ_n (fluid pressure exerted by the concrete at the time of the pour) and σ_p (atmospheric pressure = 2,116 psf) must be found. The FHWA recommends using the following equation for σ_n:

$$\sigma_n = 0.65\ \gamma_c\ z_i^* \qquad \text{Eq. 2.5}$$

where γ_c is the unit weight of concrete and z_i* is the depth to the middle point of the layer where side resistance is being calculated, with a maximum depth of 40-ft.

The FHWA recommends using the same method for calculating the base resistance for a cohesive IGM as used for finding the base resistance of rock. The following equation is provided to calculate the base resistance (q_{BN}):

$$q_{BN} = N_{CR}^*\ q_u \qquad \text{Eq. 2.6}$$

where N_{CR}^* is the empirical bearing capacity factor. It is recommended to use a lower bound value of N_{CR}^* = 2.5 ($N_{CR,\ mean}^*$ = 3.38) (Rowe and Armitage, 1987). It should be noted that when using the lower bound value of N_{CR}^*, coupled with the FHWA recommended resistance factor (φ) of 0.55, the allowable base resistance is calculated with a factor of safety of 2.5.

2.5 NAM AND VIPULANANDAN

Nam and Vipulanandan (2010) developed a relationship between TCP tests and axial resistances in rock socketed drilled shafts. Three O-Cell™ load tests were performed near Dallas, Texas; with two of the shafts socketed in clay shale (Eagle Ford Formation) and one shaft socketed in limestone (Austin Formation), as shown in Figure 2.8. Figure 2.8 profiles the TCP values and compressive strengths (MPa) with depth and in relation to the location of the load cell. Using previous studies (Aurora and Reese (1976), Seikh et al. (1985), O'Neill et al. (1992), Hassan (1994)), in addition to the information gathered from these tests, the unit skin friction and unit base resistances were modeled as a function of the TCP tests. The following relationships were developed to obtain the maximum unit side resistance (f_{max}) and maximum unit base resistance (q_{max}), in tsf, using the TCP (inches/100 blows) data available from field tests:

$$f_{max} = 13.47\ (TCP)^{-1.07} \qquad \text{Eq. 2.7}$$

$$q_{max} = 99.58\ (TCP)^{-0.79} \qquad \text{Eq. 2.8}$$

These empirical relationships are plotted in Figure 2.9, along with the current TxDOT Design Curve and data points from previous load tests. This method demonstrates that the current TxDOT design method overestimates f_{max}, while slightly underestimating the strength of soft rock (clay shale).

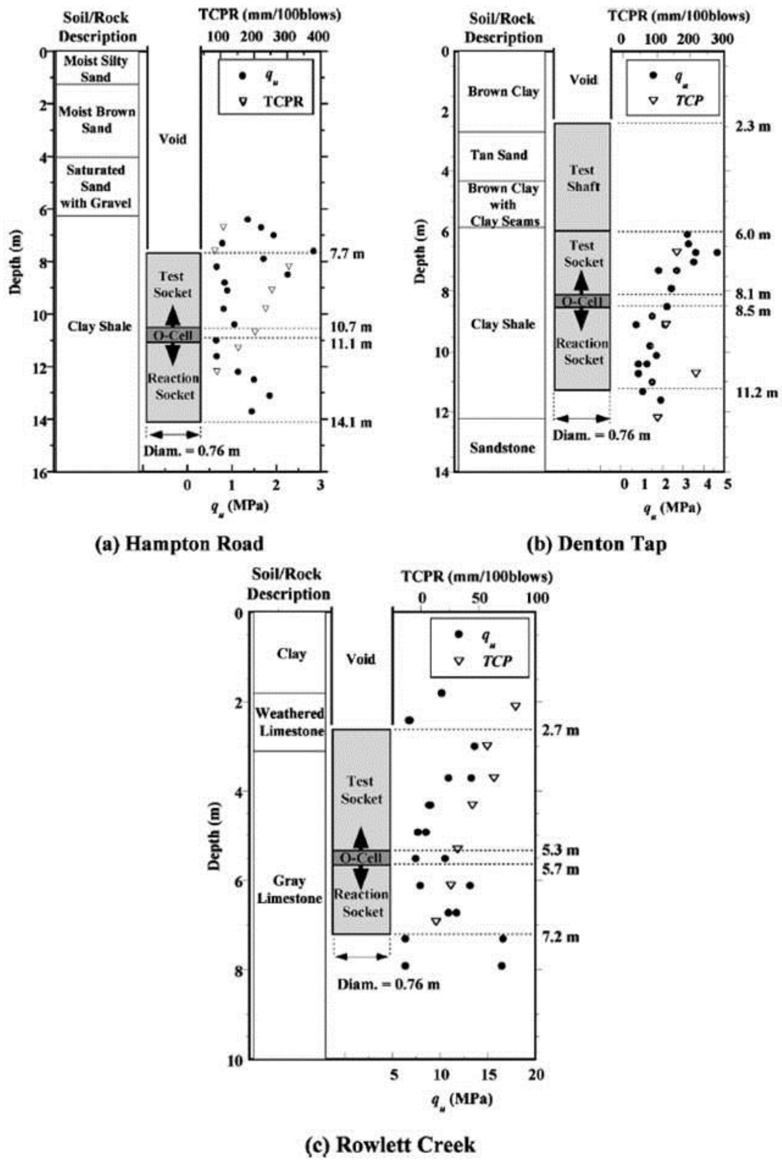
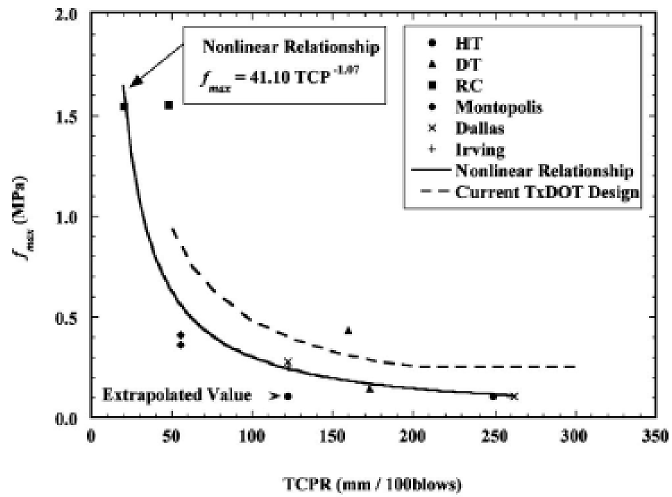


Figure 2.8: Subsurface Details for O-Cell™ Load Tests in Dallas, Texas (Nam and Vipulanandan, 2010)



(a) f_{max} versus TCPR

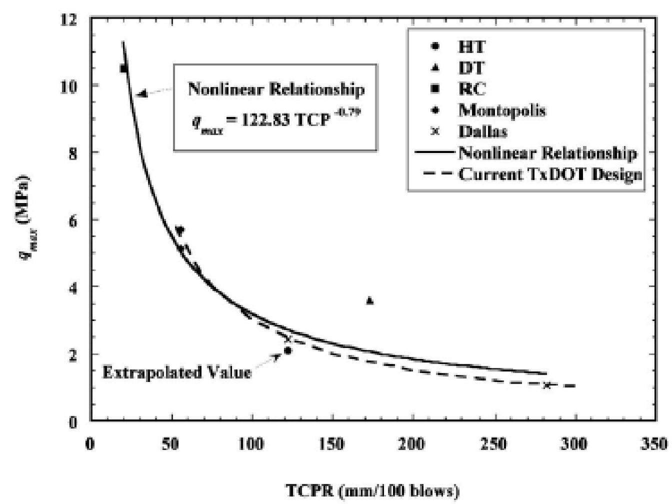


Figure 2.9: Relationship Between Ultimate End Bearing and Ultimate Side Resistance to the Current TxDOT Design Correlation and Correlation Proposed by Nam and Vipulanandan (2010)

2.6 PIERCE, LOEHR, AND ROSENBLAD

In attempt to improve correlations between in-situ soil test measurements and drilled shaft capacities, Pierce et al. (2012) installed twenty-five drilled shafts (equipped with O-Cell™ loading equipment) and performed load tests at two sites in Missouri. The main objective of the research was to establish calibrated resistance factors for use with the developed correlations of side and tip resistances of drilled shafts to in-situ soil tests. Field investigations were performed at the two sites; allowing for complete subsurface profiles strengths measured via Standard Penetration Tests (SPT) and Modified Texas Cone Penetration Tests (MTCP). The MTCP tests were performed due to the inaccessibility of a conventional, 170-lb hammer used for TCP tests, although the energy transferred from the normal SPT-sized hammer (140-lb) is similar to that required from the TCP-sized hammer.

The Pierce et al. design correlation for predicting the ultimate unit end bearing (q_p in ksf) of drilled shafts as a function of the mean MTCP value ($\overline{MTCP}$ in inches per 100 blows) for the rock beneath the shaft tip is expressed as:

$$q_p = 500\,\overline{MTCP}^{\,-1.22} \qquad \text{Eq. 2.9}$$

The correlation to predict the ultimate unit side resistance (f_s in ksf) as a function of the mean MTCP value ($\overline{MTCP}$ in inches per 100 blows) for the rock beneath the shaft tip is expressed as:

$$f_s = 31.6\,\overline{MTCP}^{\,-1.18} \qquad \text{Eq. 2.10}$$

The Pierce et al. models for predicting the ultimate unit side resistance and the ultimate unit end bearing are shown in Figure 2.10 and Figure 2.11. Also shown in the figures are the current TxDOT relationships found in the TxDOT Geotechnical Manual (2006).

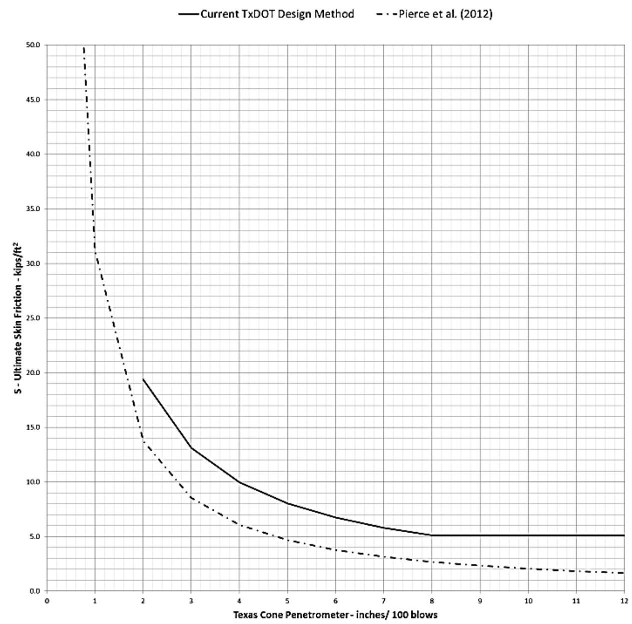


Figure 2.10: Relationship Between Ultimate Side Resistance to the Current TxDOT Design Correlation and Correlation Proposed by Pierce et al. (2012)

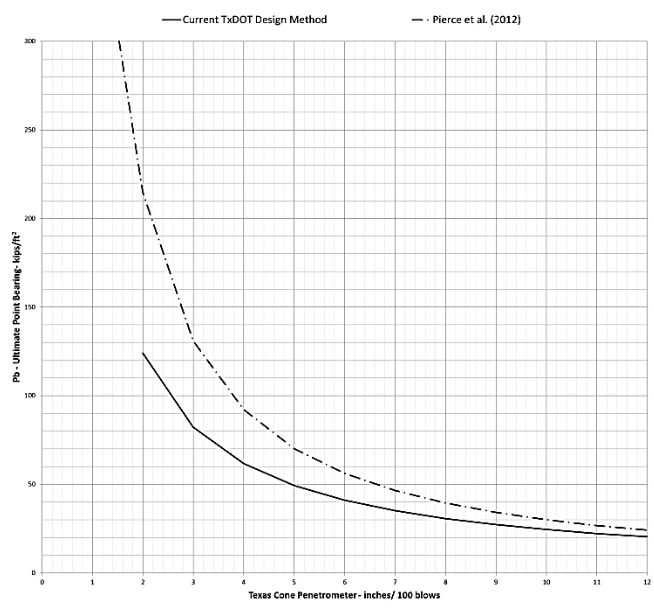


Figure 2.11: Relationship Between Ultimate End Bearing to the Current TxDOT Design Correlation and Correlation Proposed by Pierce et al. (2012)

Chapter 3:Drilled Shaft Design Methods

3.1 TXDOT DESIGN METHOD

The TxDOT Geotechnical Manual (TxDOT, 2006) contains correlations to predicting the allowable skin friction and end bearing for shaft designs where TCP tests were performed, as shown in Figure 3.1 and Figure 3.2. These figures are solely used where the TCP values are greater than 100 blows/12-inches. Figures for soils with TCP values less than 100 blows/12-inches are included in the TxDOT Geotechnical Manual, but not applicable to this study. Figure 3.1 presents the correlation of TCP test results with the allowable skin friction that is to be used in the design of drilled shafts. Figure 3.2 predicts the allowable end bearing of drilled shafts from TCP test results. It should be noted that in these figures, TxDOT has incorporated a factor of safety into calculations (FS=3 for allowable skin friction and FS=2+ for allowable end bearing). The addition of the capacities, determined from the figures, equate the design capacity of the drilled shaft.

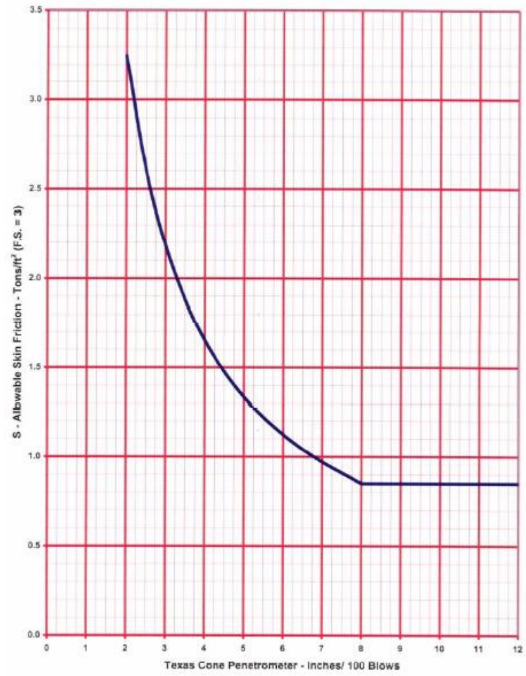


Figure 3.1: Allowable Skin Friction (TCP Values Harder Than 100 Blows/12 in.) (TxDOT, 2006)

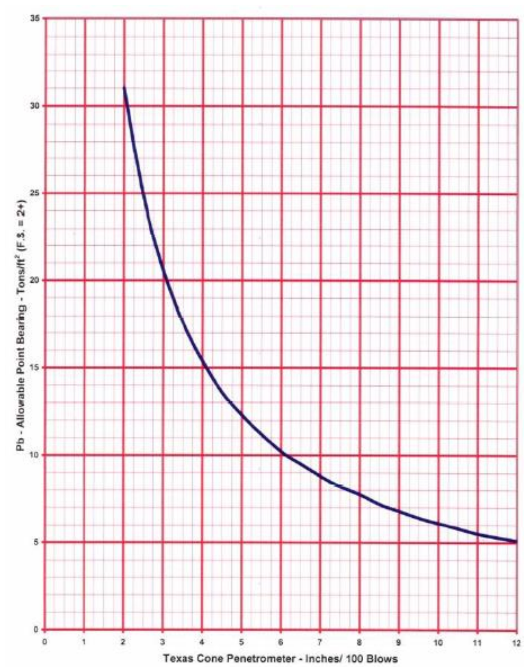


Figure 3.2: Allowable Point Bearing (TCP Values Harder than 100 Blows/12 in.) (TxDOT, 2006)

For example, consider the following 15-ft section of shale where a 2.5-ft diameter drilled shaft is to be placed (Figure 3.3). The schematics in this chapter resemble the rock sockets that are analyzed in this study. First, the skin friction of the 15-ft section is calculated. As seen in the diagram, the TCP value for this section is about 2.75-in per 100 blows. Using Figure 3.1, the allowable skin friction can be estimated as 2.4-tsf. This skin friction value is then multiplied by the perimeter of the shaft and by the depth of the section (15-ft), giving an allowable skin resistance of about 283-tons. The second step is to estimate the allowable end bearing by using the TCP value tested near the tip of the pile (2.00-in per 100 blows). Using Figure 3.2, the allowable end bearing can be estimated: 31-tsf. The allowable tip load is then found by multiplying the allowable end bearing by the cross-sectional area of the drilled shaft. The allowable tip load is about 152 tons, thus giving a total allowable capacity of about 435-tons which is to be used in the final design. The ultimate capacity predicted from the TxDOT method can be estimated by removing the factor of safety from each allowable capacity:

Ultimate Shaft Capacity: $3*F_{s,all}+2*Q_{p,\,all}$ $Q_{ult} = 1{,}153$-tons

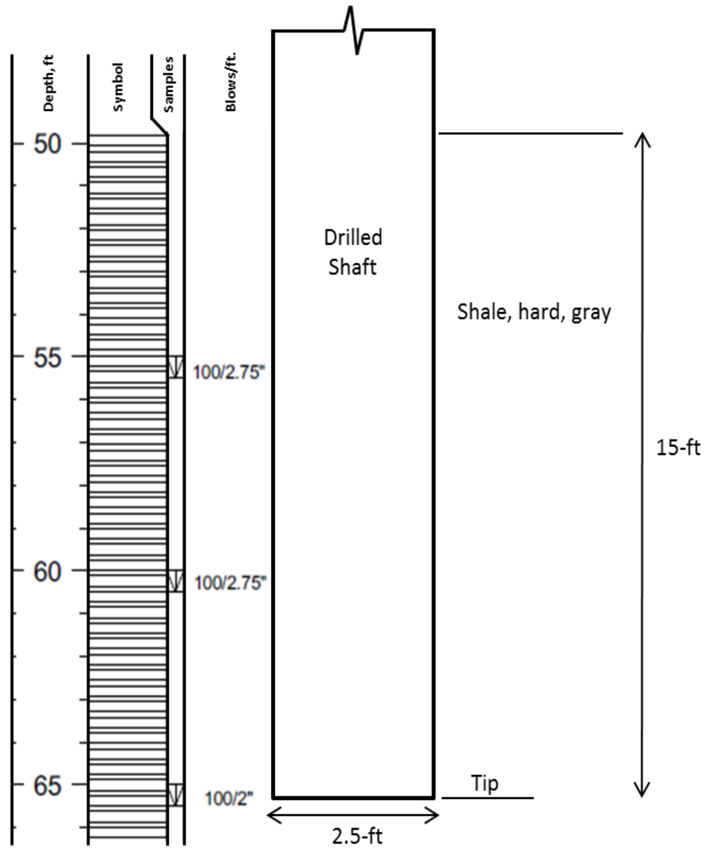


Figure 3.3: Drilled Shaft Schematic for TxDOT Method Example

3.2 FHWA DESIGN METHOD

The LRFD procedure, provided by the Federal Highway Administration (FHWA), will also be used to estimate the ultimate capacity of the drilled shafts for this study. As discussed in Section 2.4, the FHWA procedure adopted the O'Neill and Reese (1999) method for measuring the side resistance of cohesive IGM's.

To show the calculation procedure of the FHWA method, consider a drilled shaft that has been installed in a cohesive IGM, where unconfined compressive tests were performed (Figure 3.4).

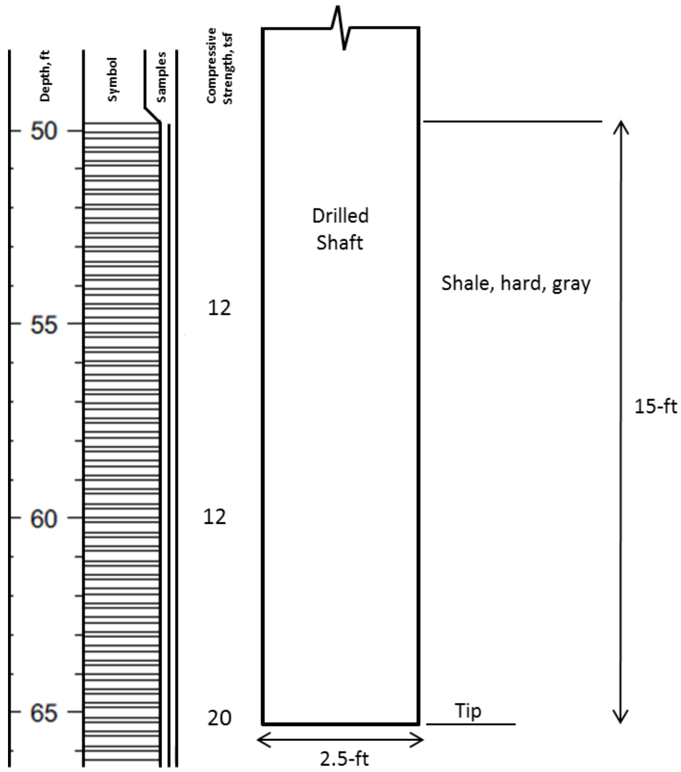


Figure 3.4: Drilled Shaft Schematic for FHWA Method Example

Assuming that the RQD is about 70%, the side resistance along the shaft is estimated using the previously mentioned formulas as follows:

From Eq. 2.5:	$\sigma_n = 0.65 * 150 \frac{\text{lb}}{\text{ft}^3} * 40 \text{ ft}$	σ_n=3,900 psf
	$\frac{\sigma_n}{\sigma_p} = \frac{3{,}900 \text{ psf}}{2{,}116 \text{ psf}}$	$\frac{\sigma_n}{\sigma_p} = 1.84$
From Figure 2.7:	q_u=12 tsf and $\frac{\sigma_n}{\sigma_p} = 1.84$	$\alpha = 0.2$
From Table 2.2 (RQD=70%):		$\varphi = 0.85$
From Eq. 2.4:	$f_{SN} = 0.2 * 0.85 * 12$ tsf	$f_{SN} = 2.0$ tsf
Nominal Side Resistance:	$F_{SN} = f_{SN} * \pi * 2.5 \text{ ft} * 15 \text{ ft}$	$F_{SN} = 240$ tons

The nominal unit base resistance and nominal base resistance are then calculated as:

From Eq. 2.6:	$q_{BN} = 2.5 * 20$ tsf	$q_{BN} = 50$ tsf
Nominal Base Resistance:	$Q_{BN} = 50 \text{ tsf} * \frac{\pi 2.5^2}{4}$	$Q_{BN} = 245$ tons

Combining the two resistances, a capacity of 485-tons is calculated for the 15-ft segment.

Chapter 4: Field Investigation

4.1 SITE LOCATION

The test site is located in southeast Austin, Texas, near the intersection of East Riverside Drive and Texas State Highway 71 (Figure 4.1). The test shafts were placed on the northern side of TX 71 (Figure 4.2), near a retaining wall that is a part of the ongoing plans to expand the highway.

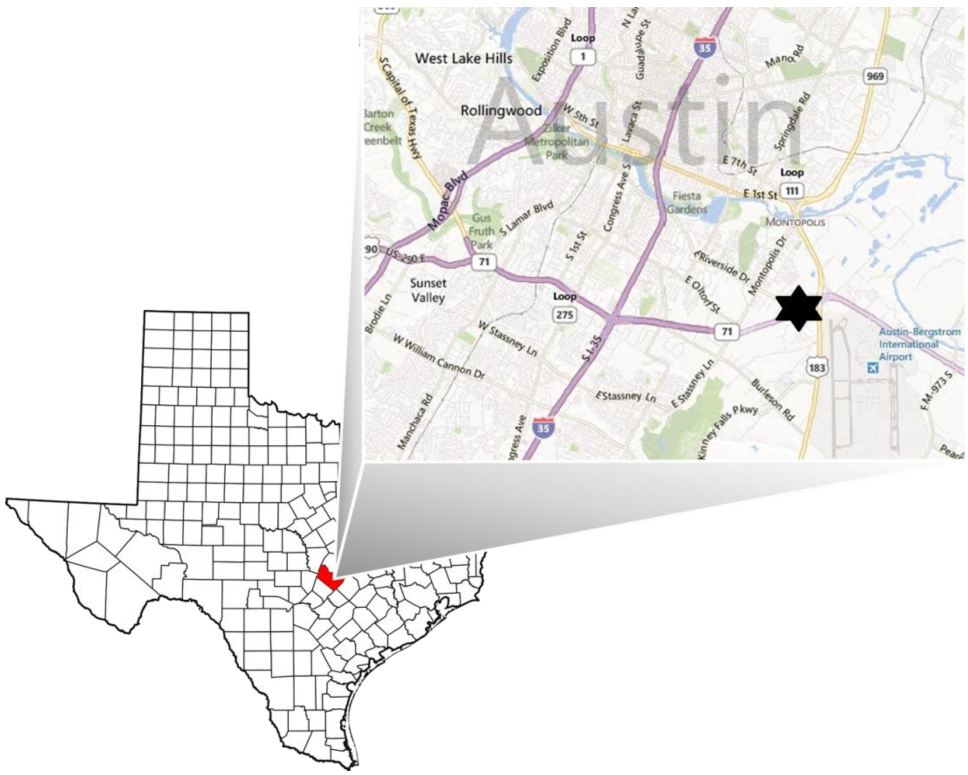


Figure 4.1: Site Vicinity

Figure 4.2: Site Location

4.2 SAMPLING AND IN-SITU TESTING METHODS

Sampling at the site consisted of in-situ and laboratory strength testing. The in-situ strength tests consisted of Standard Penetration Tests (SPT) and Texas Cone Penetrometer (TCP) Tests. Undisturbed samples of the cohesive soils were acquired either by pushing a thin-walled tube or rock coring. Obtaining undisturbed samples from the site allows for classification and unconfined compressions tests to be performed.

4.2.1 Standard Penetration Testing

Standard Penetration Testing is performed in accordance with ASTM D1586, *Standard Method for Penetration Test and Split-Barrel Sampling of Soils*. Following this procedure, a 140-lb automatic hammer is dropped from a distance of 30-inches above the anvil of the drilling rod. The field technician records the number of blows for each sampling interval, 6-in per interval, for a total of 18-in. The hammer blows during the first 6-in interval is considered "seating", while summation of blows during the second and third intervals make up the N-value of the sample (N_{SPT}). The SPT testing is stopped once the 18-in interval is reached or if 50 blows are applied over a 6-in interval. Once the testing is complete, the split barrel is brought to the surface, where it is opened, classified, and packaged.

4.2.2 Texas Cone Penetrometer Testing

Texas Cone Penetrometer (TCP) tests are performed in accordance with Tex-132-E of the TxDOT test procedures. The dimensions of a TCP are shown in Figure 4.3. When performing a TCP test, an automatic, 170-lb hammer is dropped a distance of 24-in, driving a 3-in, steel cone (Figure 4.4) into the soil. First, the cone is driven a distance of 6-in for "seating" into the sampling zone. Thereafter, the automatic hammer is triggered until the cone has been driven 12-in or 100 total blows are reached, whichever comes first. The field technician records the hammer blows for the two 6-in intervals, in which the summation equals the blow count of the material, N_{TCP}. If 100 blows are counted before the 12-in interval is reached, the length of the rod that is driven into the soil is measured and recorded. Table 4.1 shows the relationship of consistency and field identification techniques for recorded TCP values.

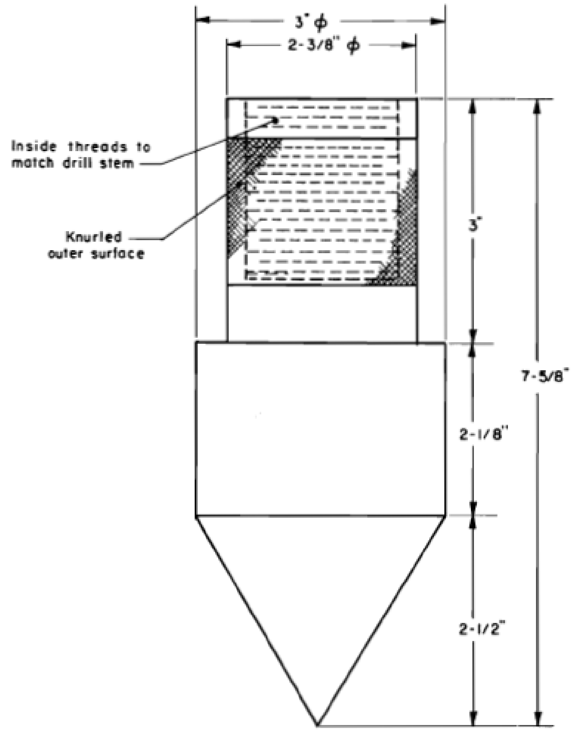


Figure 4.3: Dimensions of the Texas Cone Penetrometer (Aurora and Reese, 1976)

Figure 4.4: Texas Cone Penetrometer

Table 4.1: Soil Consistency from TCP values (TxDOT, 2006)

Consistency	TCP Value	Field Identification
Very Soft	0-8	Core (height twice diameter) sags under own weight
Soft	8-20	Core can be pinched or imprinted easily with finger
Stiff	20-40	Core can be imprinted with considerable pressure
Very Stiff	40-80	Core can be imprinted only slightly with fingers
Hard	80 to $\frac{\text{5-in}}{\text{100 blows}}$	Core cannot be imprinted with fingers but can be penetrated with pencil
Very Hard	$\frac{\text{5-in}}{\text{100 blows}}$ to $\frac{\text{0-in}}{\text{100 blows}}$	Core cannot be penetrated with pencil

4.2.3 Thin-Walled Tube Sampling

Undisturbed samples of cohesive materials are obtained by hydraulically pushing a 3-in, thin-walled tube for a distance of 2-ft. The sampling procedures are performed in accordance with ASTM D1587. Once the samples are brought to the surface, they are extruded, classified, field tested with a hand penetrometer, and packaged for transportation to the laboratory. The hand penetrometer is used by the field technician to get a rough estimate of the strength of the soil, in tsf. A look at an extruded sample of the material at the site and a hand penetrometer is shown in Figure 4.5.

Figure 4.5: Extruded Sample from a Thin-Walled Tube

4.2.4 Rock Coring

If a material is encountered in which the thin-walled tube could not be advanced, rock coring is implemented. Rock coring is performed in accordance with ASTM D2113. In order to successfully retrieve a rock sample, the field crew lowers the drilling rod, containing an outer- and inner-rod, into the bore hole. The outer-rod is tipped with a circular drill bit, while the inner-rod acts as a casing for the rock samples. The drill rig is used to push down on the sample when the resistance of the rock increases. Once an interval has been reached (usually every 5-ft), a wire-line is used to pull the inner rod to the surface. The sample, shown in Figure 4.6, is then classified, packaged, and strength tested (unconfined compression testing) where applicable.

Figure 4.6: Rock Coring Sample

Rock Quality Designation (RQD) is measured where rock coring is performed. RQD is a quick and simple way to predict the rock mass quality of the encountered materials and is performed in accordance with ASTM D6032. Figure 4.7 shows a typical rock core and how RQD can be determined. RQD is generally calculated using the following relationship:

$$\text{RQD} = \frac{\Sigma \text{ Length of Core} > 4 \text{ inches}}{\text{Total Core Length}} * 100 \qquad \text{Eq. 4.1}$$

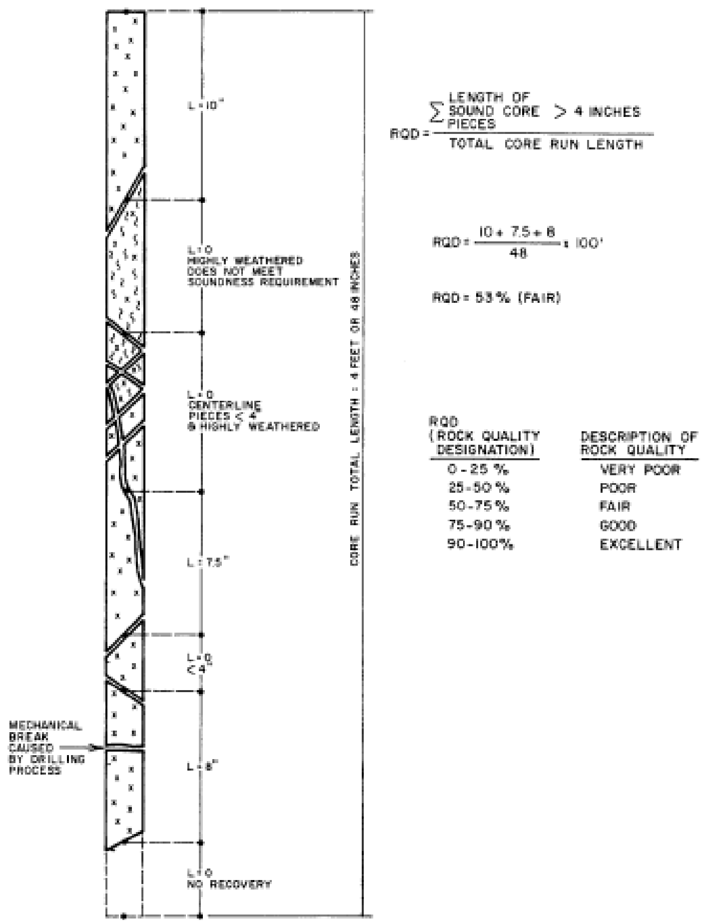


Figure 4.7: RQD Calculation (Deere, 1989)

4.2.5 Classification Testing

Classification testing includes testing and obtaining the plastic and liquid limits (Atterberg Limits) (ASTM 4318), and percent passing the No. 200 sieve (ASTM D1140). The Atterberg Limit tests provide an insight to the behavior of cohesive soils in relation to moisture content. The analysis of particles passing the No. 200 sieve is a measure of the fine-grained materials in the sample. The results of the classification tests are presented on Boring B-1 in Appendix A.

4.2.6 Unconfined Compressive Strength Testing

Using adequate rock cores obtained via rock coring, unconfined compressive (UC) tests are run in the laboratory. Performed in accordance with ASTM D2166, UC tests quickly define the strength of the samples able to be tested in the unconfined state. This nature of strength testing is performed on samples that have sufficient cohesion to allow for compression in the unconfined state. The samples were trimmed to have a length: diameter ratio of about 2.5:1. Moisture content (ASTM D2216) and dry unit weight (ASTM D2166) tests are also performed as standard measures of UC tests. The results of the UC tests run are found on Boring B-1, presented in Appendix A.

4.3 SUBSURFACE INVESTIGATION

Field testing was performed by Fugro Consultants, Inc. (Fugro) at the site to characterize the subsurface materials in which the future O-Cell™ load tests would be performed. Two boreholes, Boring B-1 and B-1A, were drilled at the site.

Boring B-1 was drilled on September 4, 2012 and advanced to a depth of 90-ft. Samples were taken at 5-ft intervals, for the first 15-ft, using a combination of SPT and hydraulically pushing a thin-walled tube. The cohesive samples, tested with the hand penetrometer, had strengths greater than the maximum possible value: 4.5 tsf. Thereafter, due to the hardness of the material, rock coring was performed, continuously, from 15- to 90-ft below the surface. Boring B-1A was drilled on October 4, 2012 and also advanced to a depth of 90-ft. TCP testing was performed at 5-ft intervals to the completion of the boring. Initially, dry-auger drilling techniques were used to obtain samples for each boring. Beginning at a depth of 15-ft below the ground surface, wet rotary drilling was implemented to complete the borings.

Each borehole was backfilled with cement-bentonite grout following the completion of the sampling procedures. The boreholes were grouted from bottom up using a tremie pipe and the boreholes were also topped off from the surface with grout. Boring logs from the field investigation are presented in Appendix A.

Figure 4.8: Field Exploration for Boring B-1

4.4 DEPTH-TO-WATER OBSERVATIONS

Each borehole was initially drilled using dry-auger drilling techniques in order to determine the depth-to-water level at the project site. Due to the hardness of the material encountered in the borings, wet-rotary drilling was implemented at a depth of 15-ft, thus, eliminating the ability to detect a water table at the time of drilling.

4.5 LABORATORY TESTING

The subsurface soils sampled from Boring B-1 were brought to the Fugro laboratory in Austin, Texas for classification and strength testing. Classification procedures such as moisture content tests, Atterberg limit tests (ASTM D4318), and sieve tests (ASTM D6913) were run in addition to Unconfined Compressive strength testing.

4.6 SOIL INTERPRETATION

The subsurface conditions explored in the project area consist of two stratums, Taylor Clay underlain by Taylor Shale. The interpreted subsurface stratigraphy from the field investigation and laboratory testing is presented in the following subsections.

4.6.1 Stratum I

Stratum I consists of Taylor Clay and ranges from the surface to a depth of about 50-ft. The tan and light gray Taylor Clay at the project site is very stiff to hard, with some calcareous pockets near the surface. Throughout the stratum, slickenside fractures were noticed, along with some ferrous staining and sand seams. At a depth of about 43.5-ft, dark gray shale seams appear as Stratum I and Stratum II begin to merge.

Moisture Contents across Stratum I ranged from 20 to 28 percent and seemed to increase with depth. Atterberg Limit were performed on two samples within Stratum I, as shown in Figure 4.9, with the following results: LL: 79-80, PL: 27, PI: 52-53. The Atterberg Limit tests indicate that the soils in Stratum I are very highly plastic.

The unit weights within the Taylor Clay range from about 97- to 104-pcf. Unconfined compression tests indicate a compressive strength ranging from 1.5- to 7.7-tsf, giving an approximate undrained shear strength ranging from 1,500- to 7,700-psf. The undrained shear strengths indicate that the Taylor Clay ranges from stiff to moderately hard.

TCP tests in Stratum I were conducted on 5-ft intervals from the ground surface to the bottom of the stratum. The blow counts ranged from 24 to 79 blows (per 12-in of cone penetration). At the transition zone of 45- to 50-ft, the cone was driven a distance of 10.25-in when 100 blows were recorded. As shown previously in Table 4.1, the Taylor Clay ranges from stiff to very stiff, with the soil becoming hard in the transition zone.

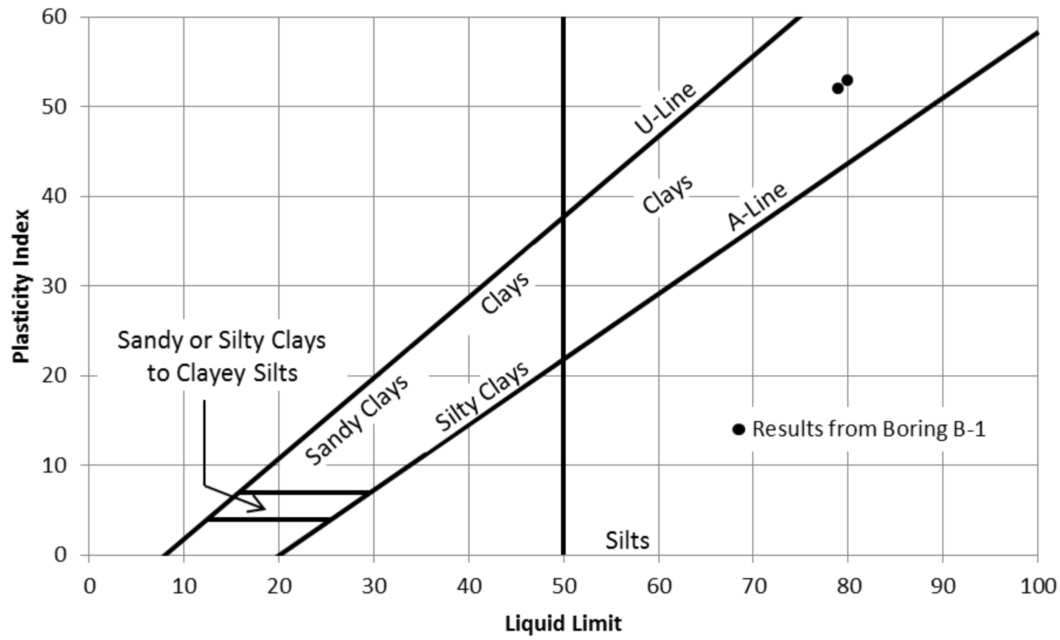


Figure 4.9: Plasticity Chart for Atterberg Limits Performed on Taylor Clay Samples from Boring B-1

4.6.2 Stratum II

Stratum II consists of Taylor Shale; ranging from a depth of about 50- to approximately 90-ft below the ground surface, the maximum depth explored in the field exploration. The dark gray Taylor Shale has low to moderate hardness and slightly fissured. Throughout the stratum, slickenside fractures were noticed, along with occasional ferrous stained fractures.

Moisture Contents across Stratum II ranged from 16 to 20 percent, with unit weights ranging from about 106- to 117-pcf. Unconfined compression tests indicate a compressive strength ranging from 6.9- to 20-tsf, giving an approximate undrained shear strength ranging from 6,900- to 20,000-psf. The undrained shear strengths indicate that the Taylor Shale ranges from moderately hard to very hard. High variations of compressive strengths in the Taylor Shale are most likely due to the many fissures and inconsistencies that exist in the stratum as described in Aurora and Reese (1976):

- *As soon as the sample is removed from its natural state, the release of confining pressures causes micro- and macro- fissures to form. Due to these fissures, the shear strength measured by laboratory tests may be significantly lower than the actual in-situ shear strength. The extent of strength variation due to fissures cannot be precisely determined.*
- *Progressive changes in soil properties, as well as further increase in the amount of fissures and cracks, occur during storage of samples.*

TCP tests in Stratum II were conducted on 5-ft intervals from about 50-ft below the ground surface to a depth of about 90-ft. The blow counts ranged from about 5- to 0.75-in per 100 hammer blows. From the soil consistency descriptions in Table 4.1, the Taylor Shale ranges from hard to very hard.

4.6.3 Subsurface Profile

The subsurface profile at the project site is presented in Figure 4.10. The figure shows UC test results, as well as TCP blow count values (N_{TCP}), with relation to depth and elevation. Two Atterberg Limit tests were run on Taylor Clay samples obtained from Boring B-1 (Figure 4.9). The results indicate that the soils in Stratum I are very highly plastic.

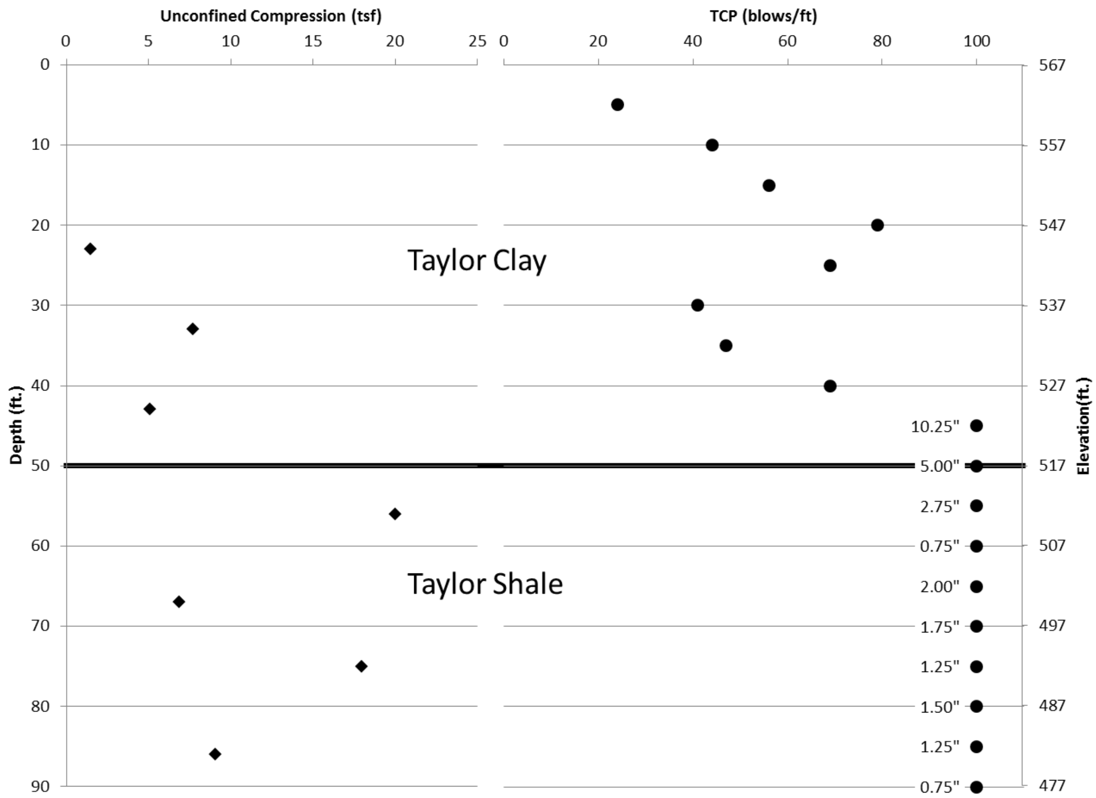


Figure 4.10: Subsurface Profile Including UC and TCP Test Results

Chapter 5: Load Test Design

5.1 General O-Cell™ Instrumentation

As stated previously, the O-Cell™ is a sacrificial load cell that is placed, at depth, within the test shaft. The O-Cell™ is equipped with instrumentation to measure the displacement of the shaft. The movement of the shaft is measured though a combination of linear vibrating wire displacement transducers (LVWDT) and electronic dial gauges. Four LVWDTs are welded to the top and bottom steel plates, symmetrically around the O-Cell™. The average of the LVWDTs gives the extension of the O-Cell™ at any point in time. Those measurements, coupled with the displacement of the electronic gauges attached to tell-tales at the surface, provide the movement of the upper shaft. This information, along with strain gauge data, is crucial in creating a t-z curve (side resistance vs. movement) for the shaft-soil interaction. All electronic gauge readings are recorded at the surface through a networked data acquisition system.

Strain gauges, donated to the project by Ensoft, Inc. (Ensoft), are placed at multiple vertical locations in the concrete adjacent to the soil-shaft areas of interest. The gauges record the axial strain imposed on the concrete shaft from the load cell. The strain is then converted to load, using the Young's modulus of the concrete and the dimensions of the shaft. Knowing the load dissipation throughout the length of the shaft provides the load transferred to the adjacent shale, thus allowing the creation of side resistance vs. movement plots for the shaft-soil interaction. The data gathered from the strain gauges is collected by a data acquisition system set up by Ensoft.

5.2 Test Shaft Locations

Through communication between the University of Texas and TxDOT research teams, the two test shafts were decided to be installed in the vicinity of Retaining Wall E

(RWE); just north of westbound TX 71. The new highway construction for TX 71 involves depressing the current TX 71 and adding RWE to support to the Taylor Clay that will remain upright, bordering the highway. The location of the test shafts, in relation to the alignments and proposed highway plans used by TxDOT, is presented in Figure 5.1. Since the site location is in close vicinity of RWE, the test shafts must be placed in the middle of the soldier pile stations, as shown in Figure 5.2; avoiding the future tiebacks that were to be installed into RWE. With the completion of this study, the test shafts will remain located within RWE, but not used as production shafts.

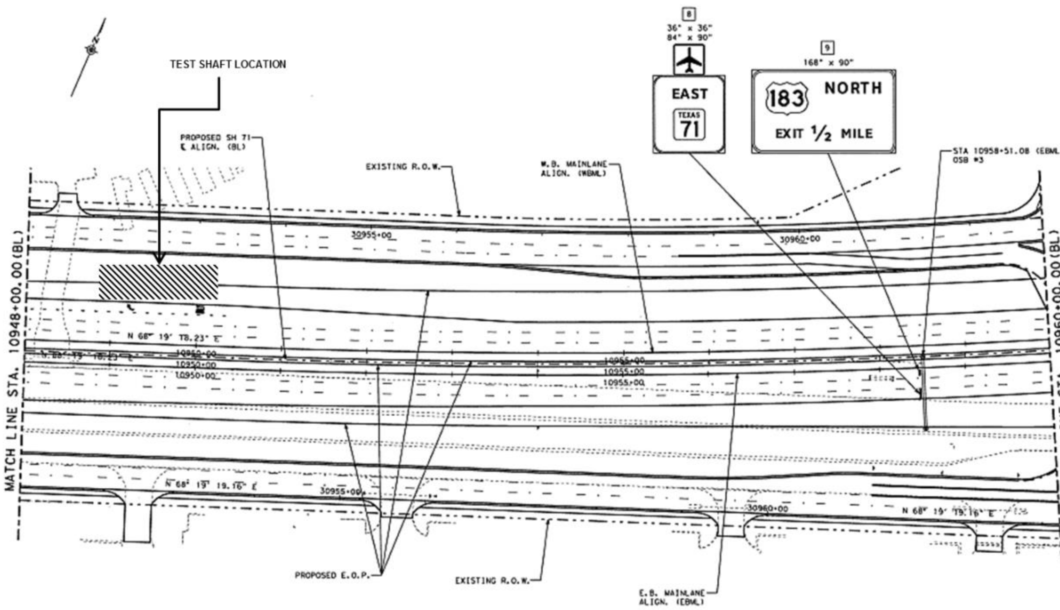
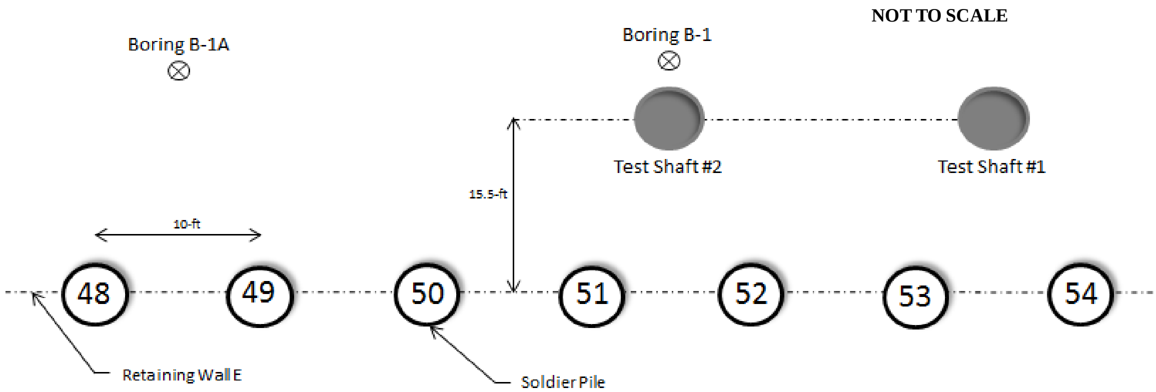


Figure 5.1: Test Shaft Location in Relation to TxDOT Proposed Highway Plans



Soldier Pile	Station*
48	10949+46
49	10949+56
50	10949+66
51	10949+76
52	10949+86
53	10949+96
54	10950+06

Structure	Station*
Test Shaft #1	10950+01, 15.5' LT
Test Shaft #2	10949+81, 15.5' LT
Boring B-1	10949+81, 20.0' LT
Boring B-1A	10949+51, 20.0' LT

*Alignment: Westbound Main Lane

Figure 5.2: Plan View of Test Shaft and Boring Layout in Relation to Alignment: West Bound Main Lane

5.3 O-CELL™ PLACEMENT AND ASSEMBLY

O-Cell™ devices are designed in many capacities and sizes (1,100-ton/20-in O-Cell™ is used in this study). With these limitations in mind, it makes the placement of the O-Cell™ critical. The O-Cell™ can be pressurized until one of three limitations are met: the ultimate skin resistance in the upper shaft is reached, the sum of the ultimate skin resistance and end bearing in the lower shaft is reached, or the maximum load capacity of the O-Cell™ is reached. If the O-Cell™ is placed too high in the shaft (the upper shaft plunges prior to the lower shaft), the end bearing of the shale will not be fully mobilized. This would be the worst case scenario for this study, considering that mobilizing the end bearing in the shale is an important objective for the research. The other scenario would be if the O-Cell™ was placed too low in the shaft (the lower shaft plunges without any movement in the upper shaft). Both scenarios are not desirable to our research. Ideally, both shafts should meet the ultimate resistance at the same time, therefore, fully mobilizing the end bearing and skin fiction (above and below the cell). It was concluded that the O-Cell™ would be placed at a level in the shaft where the resistance of the upper shaft was about three times larger than the resistance of the lower shaft. This placement would provide some comfort room to surely mobilize the end bearing, while still partially mobilizing the upper shaft.

A preliminary challenge in this study was to select an adequate depth to place the O-Cell™ in order to mobilize both portions of the shaft; the lower shaft side resistance and end bearing and the upper shaft side resistance. The decision was made to install Test Shaft #2 after the load test of Test Shaft #1 has been completed, allowing corrections to be made in the load cell placement depth after the initial test. Using the established design methods discussed earlier and through collaboration of the research team, it was decided to place the load cell in Test Shaft #1 at a depth of 7-ft above the tip. This depth was decided on assuming that the side friction of the upper shaft (73-ft) would be three times greater than the sum of the side friction and end bearing in the lower shaft, thus causing failure in the lower shaft. After the completion of the first load test, it was determined that the O-Cell™ could be moved to a shallower level, due to the response measured under loading. It was determined to place the O-Cell™ at 10-ft above the tip in Test Shaft #2. A schematic of the O-Cell™ placement within the two test shafts is shown in Figure 5.3 (a) and (b).

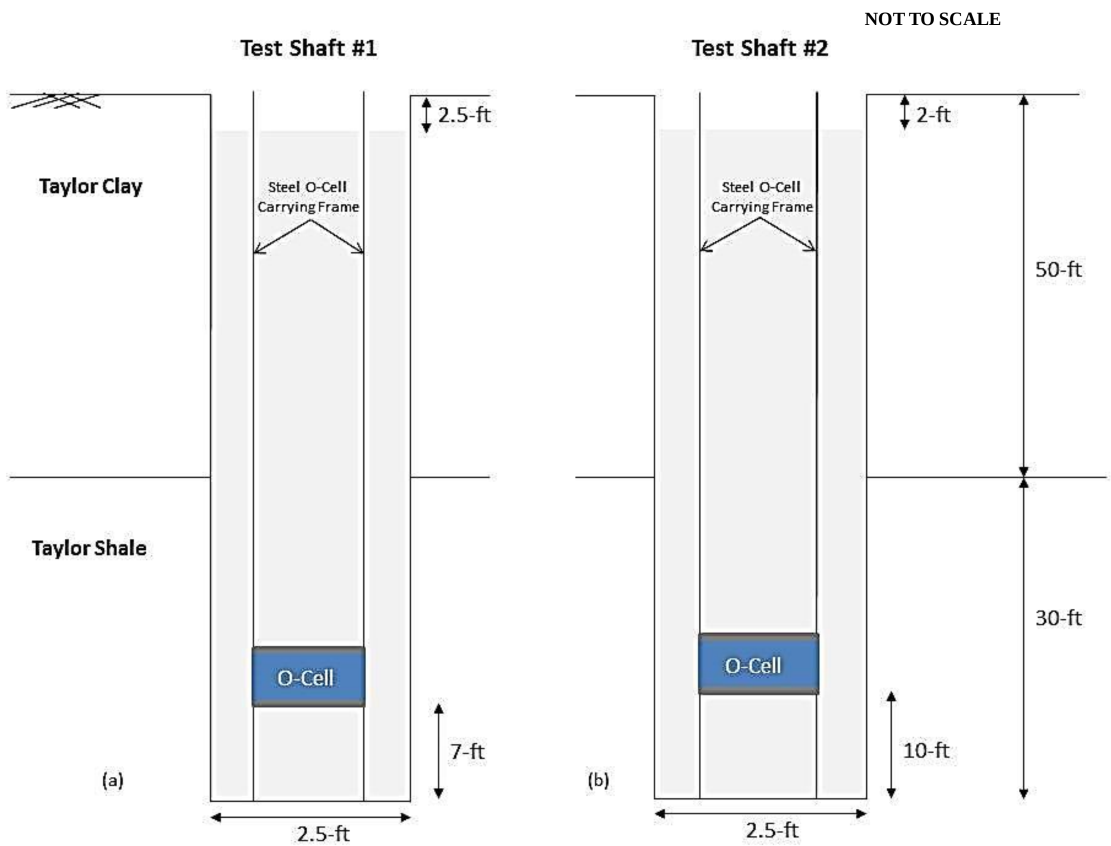


Figure 5.3: Location of O-Cell™ for (a) Test Shaft #1 and (b) Test Shaft #2

5.4 LOADING PROCEDURE

The test shafts are loaded in accordance with ASTM D1143 using Procedure A: Quick Test. The ultimate objective to the test is finding more information in the Taylor Shale, thus the focus will be on reaching the ultimate load of the lower shaft in each test. Readings are taken every 1, 2, 4, and 8 minutes during each loading increment. The failure criteria for the skin friction and end bearing in Taylor Shale are generally unknown. Therefore, an estimation of the capacity of the shaft below the O-Cell™ must be made based on the current design methods. Table 5.1 presents the predicted ultimate capacities for the 7-ft rock socket of Test Shaft #1 and the 10-ft rock socket of Test Shaft

#2, using the current TxDOT and FHWA design methods (discussed in Sections 3.1 and 3.2):

Table 5.1: Predicted Ultimate Capacities for Rock Sockets of Test Shaft #1 & #2 (units: kips)

		TxDOT	**FHWA**
Test Shaft #1	Side Resistance	1,070	187
	End Bearing	610	245
	$Q_{ultimate}$	**1,680**	**432**
Test Shaft #2	Side Resistance	1,530	267
	End Bearing	610	245
	$Q_{ultimate}$	**2,140**	**512**

It should be noted that the FHWA resistance was calculated using a conservative q_u value of 10-tsf, due to the erratic nature of the compressive strength test results in the Taylor Shale. Measured values for the compressive strength in the Taylor shale ranged from about 7- to 20-tsf.

The loading procedures in this study include an initial loading cycle, followed by an unloading, then a final reload. It was determined that the initial loading cycle would proceed to a load near the design (allowable) capacity of the rock socket in each shaft. This load would be predicted, using the current TxDOT design method, by applying a factor of safety used in the TxDOT Geotechnical Manual (FS = 3 for side resistance and FS = 2 for end bearing) to the ultimate values shown in Table 5.1.

Chapter 6:Data Analysis

6.1 O-CELL™ LOAD VS. DISPLACEMENT

As the O-Cell™ pressurizes, the expansion of the cell places a load on each shaft, moving them in opposite directions. The loading causes the upper shaft to move upwards, being resisted solely by skin friction, while the lower shaft is moving downwards against a combination of skin friction and end bearing. Using the displacement information and load cell readings, two load-displacement curves can be created for the upper and lower shafts, as shown in Figure 6.1. The two curves start at 0.0-in, when the O-Cell™ is still compressed. As the O-Cell™ begins to extend, the load increases and the shafts begin to move. The upper shaft displacement is plotted in relation to the net load (upwards load minus the buoyant weight of the shaft) being applied by the O-Cell™. The lower shaft displacement is plotted against the gross load of the load cell. As previously mentioned, the location of the O-Cell™ was chosen to make certain that the lower shaft failed prior to the upper shaft, thus explaining the extreme amount of difference in the mobilization of the upper and lower shafts. Once the shaft begins to plunge, the O-Cell™ is pressurized until it has extended about 6-in; the maximum stroke for the load cells used in this study.

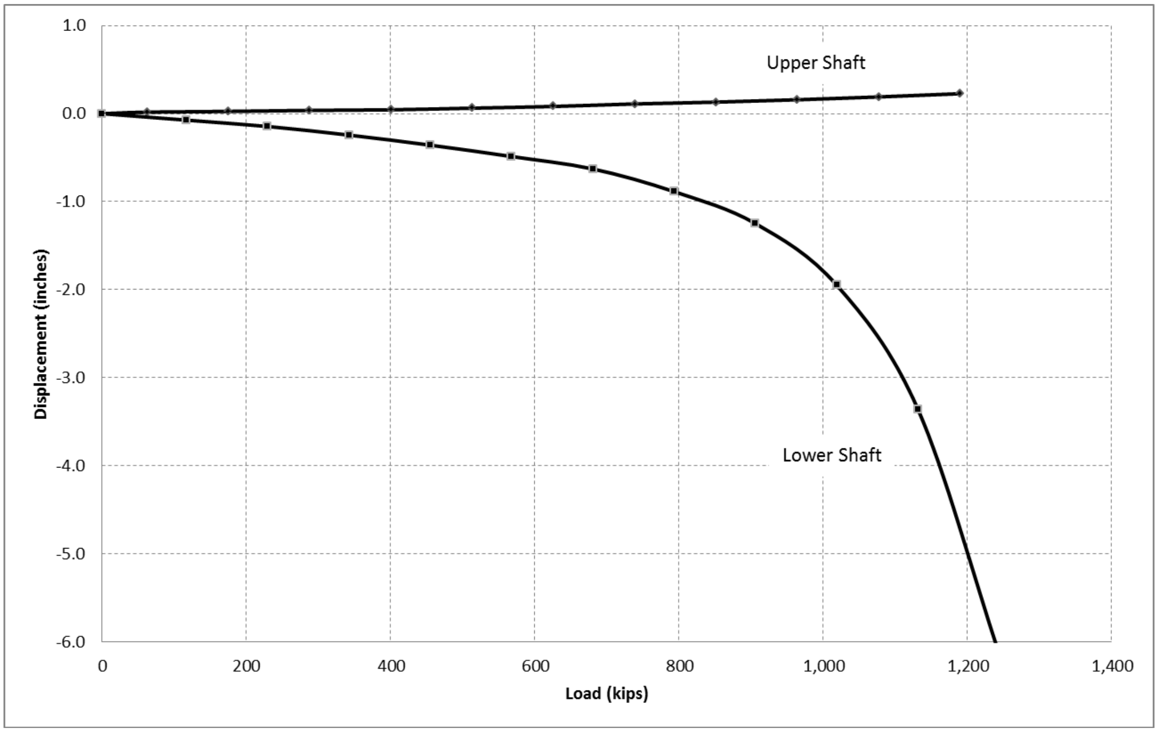


Figure 6.1: Load vs. Displacement Curve for Test Shaft #1

6.2 Top-Loaded Load-Settlement Curve

Using the results from the load-displacement plot shown in Figure 6.1, an equivalent "top-loaded load-settlement" curve can be created; depicting the load-settlement relationship had the entire shaft been conventionally loaded at the top of the shaft. The procedure was created by Loadtest using the following assumptions related to this study (Loadtest, 2000):

- The side shear load-movement curve in a top-loaded shaft has the same net shear, multiplied by an adjustment factor "F", for a given downward movement as occurred in the O-Cell test for that same movement at the top of the cell in the upward direction. (F=1.00 for primarily cohesive soils in compression),

- The pile is assumed to behave as a rigid body, but elastic compression data obtained for the load test are used to correct for additional elastic compressions in a top-load test, and
- The lower shafts are assumed to have the same load-movement behavior as when top-loading the entire shaft.

The top-loaded curve is constructed by first selecting a shaft displacement value, then locating the corresponding loads that caused the upper and lower shafts to move to that displacement (Figure 6.2). This process is the completed for each settlement value to give the total top-loaded load-settlement curve. It should be noted that the elastic compression in the equivalent top-down test is greater than the elastic compression during an O-Cell™ test. The basis of this assumption is due to the load being applied at the top of the shaft in a top-down test, where the unit side shear is the weakest and the elastic compression is the greatest. However, this is the opposite for the O-Cell™ load test; the load is applied where the unit side shear is the largest and the elastic compression is the least. With this in mind, Loadtest offers an approximate solution to account for the additional elastic compression that should be included in a top down load test. This approach involves finding the approximate elastic compression for a top-down load test (δ_{TLT}) and the elastic compression for an O-Cell™ load test (δ_{OLT}). The difference in the elastic compression of both testing methods (δ_{TLT} - δ_{OLT}) gives the desired additional elastic compression at the top of a top-down load test. The value is calculated for each load of interest and then added to the top-down load of the "rigid" shaft to obtain the corrected, equivalent top-loaded load-settlement curve.

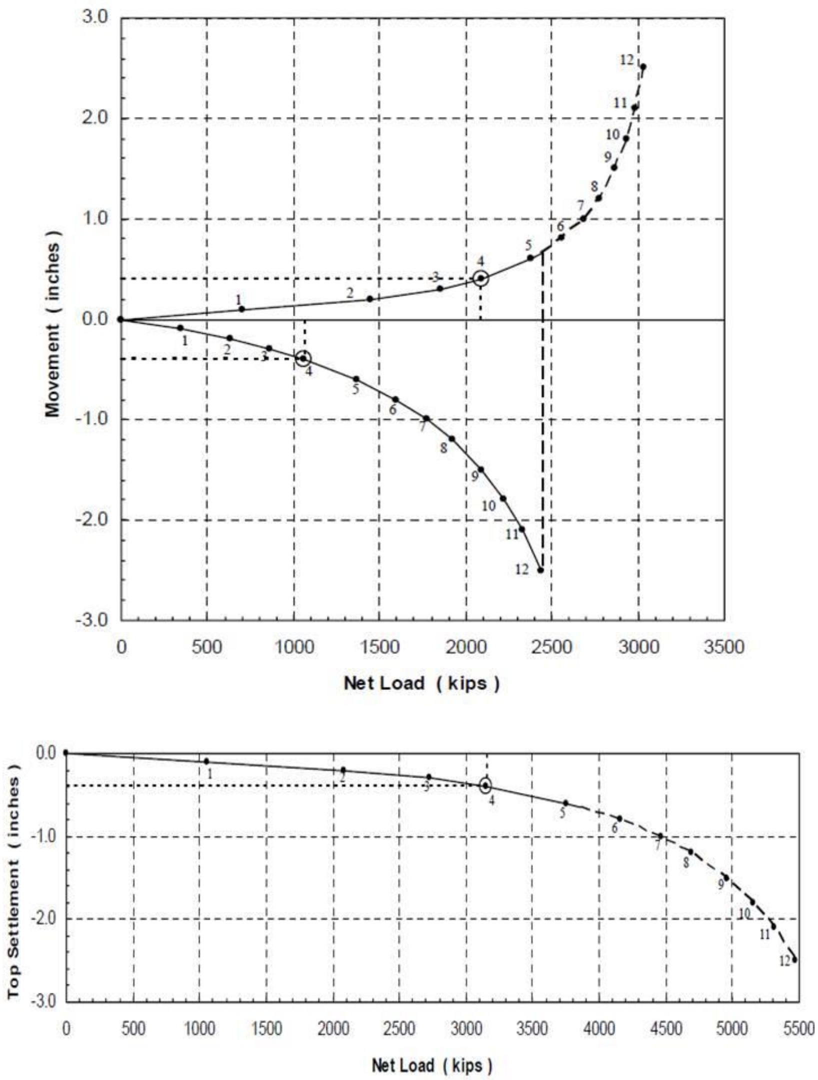


Figure 6.2: Top-Loaded Load-Settlement Curve Calculation Example

6.3 CREEP LIMIT

The creep limit, the load at which pile displacement continues freely under a constant load, can be determined from the load vs. displacement data. The displacement during a set time interval (4 to 8 minutes for this study) is recorded during testing and plotted with the corresponding load being applied. If no apparent creep is present, the data generally shows a relationship as shown in Figure 6.3. For situations where creep is occurring, the curve is generally flat until the point at which significant displacement occurs under sustained loading. The curve is then broken into two parts; with trend lines representing the plotted data (Figure 6.4). The intersection of the trend lines defines the creep limit.

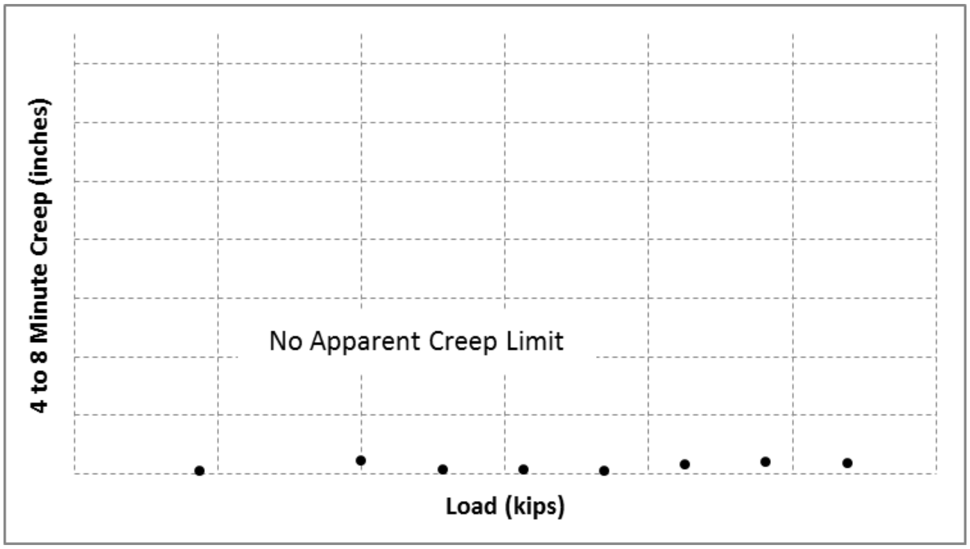


Figure 6.3: Typical Creep Limit Plot with No Apparent Creep Limit

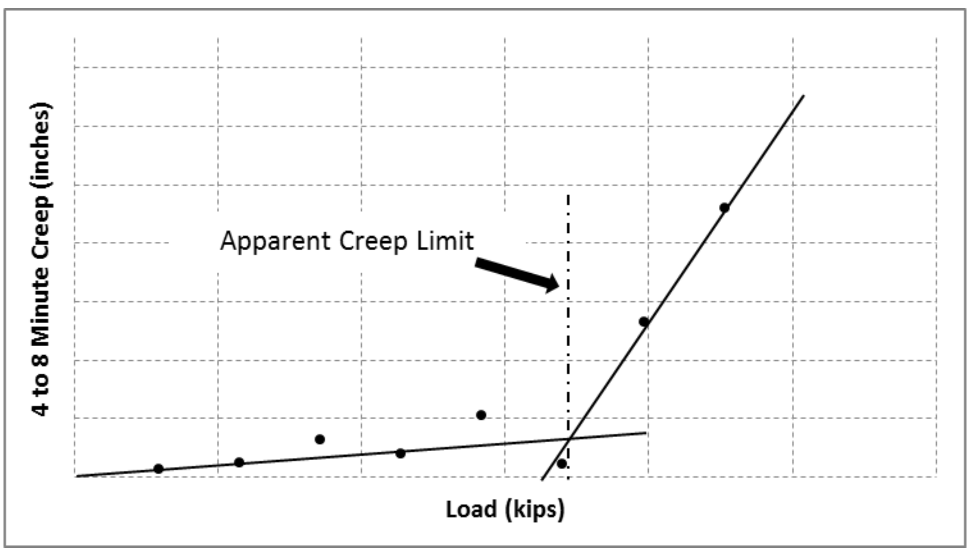


Figure 6.4: Typical Creep Limit Plot with an Apparent Creep Limit

6.4 MEASURING SKIN FRICTION AND END BEARING

The skin friction can be computed from the difference in strain registered from the strain gauges in the shaft. The geometric properties of the pile must be known, as well as the material properties, such as Young's modulus (E). For concrete, Young's Modulus is generally determined from the 28-day compressive strength of the concrete (f_c'), using the ACI formula:

$$E\,(\text{psi}) = 57{,}000\sqrt{f_c'(\text{psi})} \qquad \text{Eq. 6.1}$$

The stress (σ) on the shaft at the strain gauge location can be calculated using the Young's Modulus of the concrete and the registered strain (ε):

$$\sigma = E\varepsilon \qquad \text{Eq. 6.2}$$

Knowing that stress is defined as load (P) per area (A), the load that is registered at the location of each strain gauge can be calculated:

$$P = AE\varepsilon \qquad \text{Eq. 6.3}$$

This will provide a load distribution throughout the shaft, which corresponds to the loading increment being applied by the O-Cell™. The difference in load between neighboring strain gauges is the amount of load that is transferred into the adjacent soil: the total skin resistance (Q_S). Knowing the distances between adjacent strain gauges (ΔL) and the diameter of the pile (D), the surface area (A_S) of the pile (between the strain gauges) can be calculated:

$$A_s = \Delta L \pi D \qquad \text{Eq. 6.4}$$

From here, the unit skin friction is calculated as the change in load (ΔP) over the corresponding surface area between the gauges:

$$f_s = \frac{\Delta P}{A_s} \qquad \text{Eq. 6.5}$$

A skin friction value can be calculated for each loading increment and movement at each strain gauge location in the pile. A compilation of these values will create a t-z curve (Figure 6.5) describing the magnitude of the unit skin friction as the pile is being mobilized.

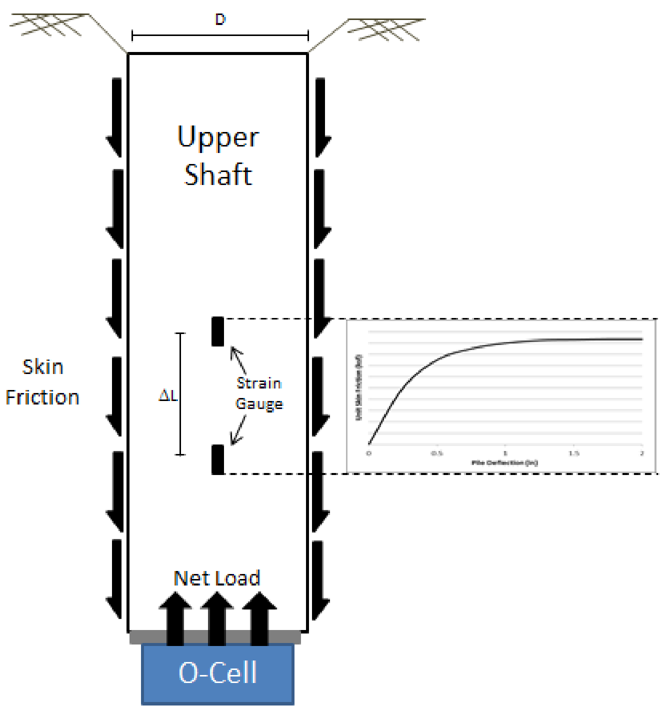


Figure 6.5: Upper Shaft Diagram, with Typical T-Z Curve Obtained Between Two Strain Gauge Levels

The strain gauges placed near the pile tip provides the information needed to estimate the end bearing of the test shafts. The strains recorded at the tip are converted to kips (Q_p) in the same manner as previously mentioned, then divided by the cross-sectional area (A_{tip}) of the shaft to provide the unit end bearing (q_p):

$$q_P = \frac{Q_P}{A_{tip}} \qquad \text{Eq. 6.6}$$

A unit end bearing value can be calculated for each loading increment and movement of the tip, creating a tip resistance vs. displacement plot (q-z curve). Finding the relationship of the unit skin resistances with displacement will lead to many new design considerations for shafts founded within the Taylor Shale.

Chapter 7: Construction of Test Shafts

7.1 TEST SHAFT #1

7.1.1 Construction of Test Shaft

Test Shaft #1 (TS #1) was installed on August 23rd and 24th, 2012. The research team decided to place TS #1 between soldier piles No. 53 and No. 54 of RWE. The center of the drilled shaft was placed 15.5-ft from the centerline of RWE, avoiding disturbance of the future wall. McKinney Drilling, Co. (McKinney) drilled the 30-in shaft on the morning of August 23rd, shown in Figure 7.1. The shaft was drilled without the use of casing and by means of the dry method. At a depth of about 40- to 45-ft below grade, dark gray shale cutting began to emerge, confirming the depth of Stratum II. The drilling continued to a depth of about 80-ft, leading to the base being visually inspected and a weighted tape being lowered to confirm the final depth. No water table was detected throughout the entire depth of drilling. Drilling was then stopped while the O-Cell™ frame was assembled.

The O-Cell™ was shipped to the site by Loadtest, along with various other assembly parts needed for installation. Before the O-Cell™ could be installed, two 2-in steel plates needed to be welded on the top and bottom of the load cell as shown in Figure 7.2. The steel disks allow the load to be distributed at a wider diameter into the concrete shaft, while also allowing concrete to flow to the bottom of the shaft during the concrete pour.

A carrying frame was constructed to securely lower the O-Cell™ to the correct depth of the drilled shaft. Once the carrying frame and O-Cell™ have been welded together, four linear vibrating wire displacement transducers (LVWDT) are welded to the O-Cell™, as shown in Figure 7.3, to measure the extension of the O-Cell™ as load is applied. Two ventilation and two compression pipes extended from the top of the carrying frame to the load cell. The ventilation pipes were welded to the bottom steel plate, allowing compressed air to escape from underneath the O-Cell™. The compression pipes extended to the top steel plate and contained a tell-tale inside, measuring the movement of the top of the O-Cell™ (bottom of the upper shaft) during loading. Figure 7.4 shows the finalized assembly of the O-Cell™ accessories.

Figure 7.1: Drilling of Test Shaft #1 with Taylor Clay and Taylor Shale Cuttings

Figure 7.2: O-Cell™ with Steel Plates Welded to Top and Bottom

Figure 7.3: LVWDTs attached to the side of the O-Cell™, measuring the extension of the O-Cell™ under loading

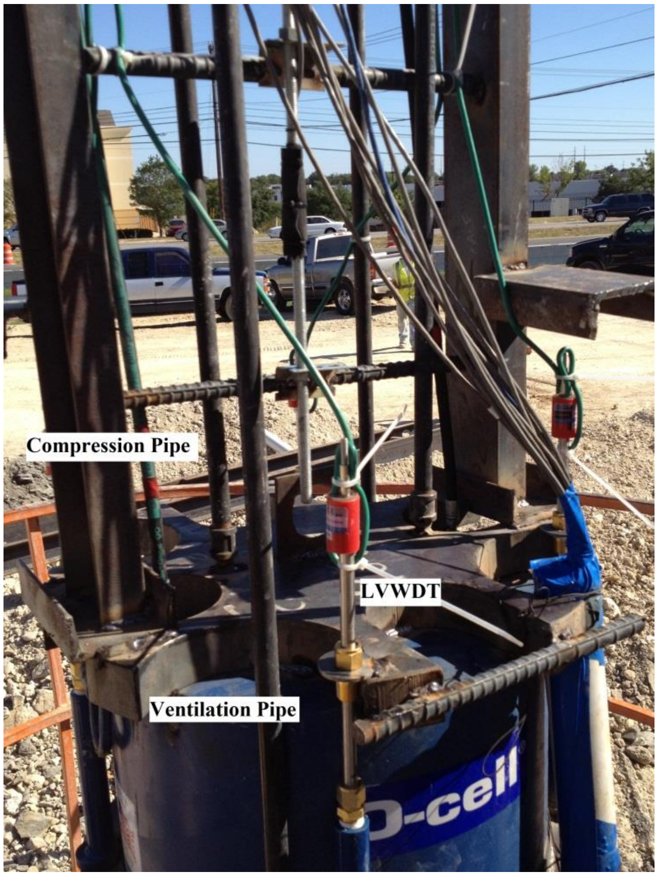


Figure 7.4: O-Cell™ Assembly: Compression Pipe, Ventilation Pipe, and LVWDT

As discussed in Section 5.3, the O-Cell™ in TS #1 was installed at a depth of about 73-ft below grade (7-ft above the tip of the shaft). Therefore, an 80-ft carrying frame was constructed that spanned the entire upper drilled shaft, along with a few feet of the carrying frame sticking above ground. A 7-ft lower carrying frame was welded to the bottom steel plate of the O-Cell™ (Figure 7.5), which acted as a support for the strain gauges that were placed in the lower shaft. Also, the lower frame assisted in correctly placing the O-Cell™ at the planned depth.

Figure 7.5: Welding the Upper Carrying Frame and O-Cell™ to the 7-ft Lower Carrying Frame

Attached to the sides of the carrying frame were the electrical strain gauges, used to record the microstrains within the concrete, during loading. The gauges were wire-tied to a steel bracket, which was then welded to the side of the carrying frame as shown Figure 7.6. The gauges were placed at many levels within the Taylor Shale. It should be noted that some of the strain gauges were unresponsive during the load testing. It is assumed that the affected gauges were disrupted during the pouring of the concrete. Those gauges are shown on the Loadtest Report of TS #1 in Appendix B, but not discussed further.

Figure 7.6: Attachment of Strain Gauges to the O-Cell™ frame for Test Shaft #1

After the O-Cell™ assembly was complete, but before lowering, the preliminary concrete pour took place. This was done to allow a free flow of concrete to fill the area where the lower shaft would be, prior to placement of the frame. The main objective of this strategy was to allow concrete to easily fill the portion of the shaft below the O-Cell™, without requiring the concrete to seep around the steel disks and O-Cell™. The concrete was poured until the field crew measured just over 7-ft of concrete in the hole. Afterwards, the O-Cell™ frame was then lowered into the hole, pushing the lower frame (equipped with strain gauges) into the pre-poured concrete. Once in place, the remaining concrete was added to the hole by the "free-fall" method, leaving about 2.5-ft of space between the top of shaft and the ground surface (Figure 7.7). The final as-built diagram for Test Shaft #1 is shown in Figure 7.8, with elevations and depths of interest presented in Table 7.1.

Figure 7.7: O-Cell™ Frame after Concrete Pouring (Concrete Depth is 2.5-ft Below the Ground Surface)

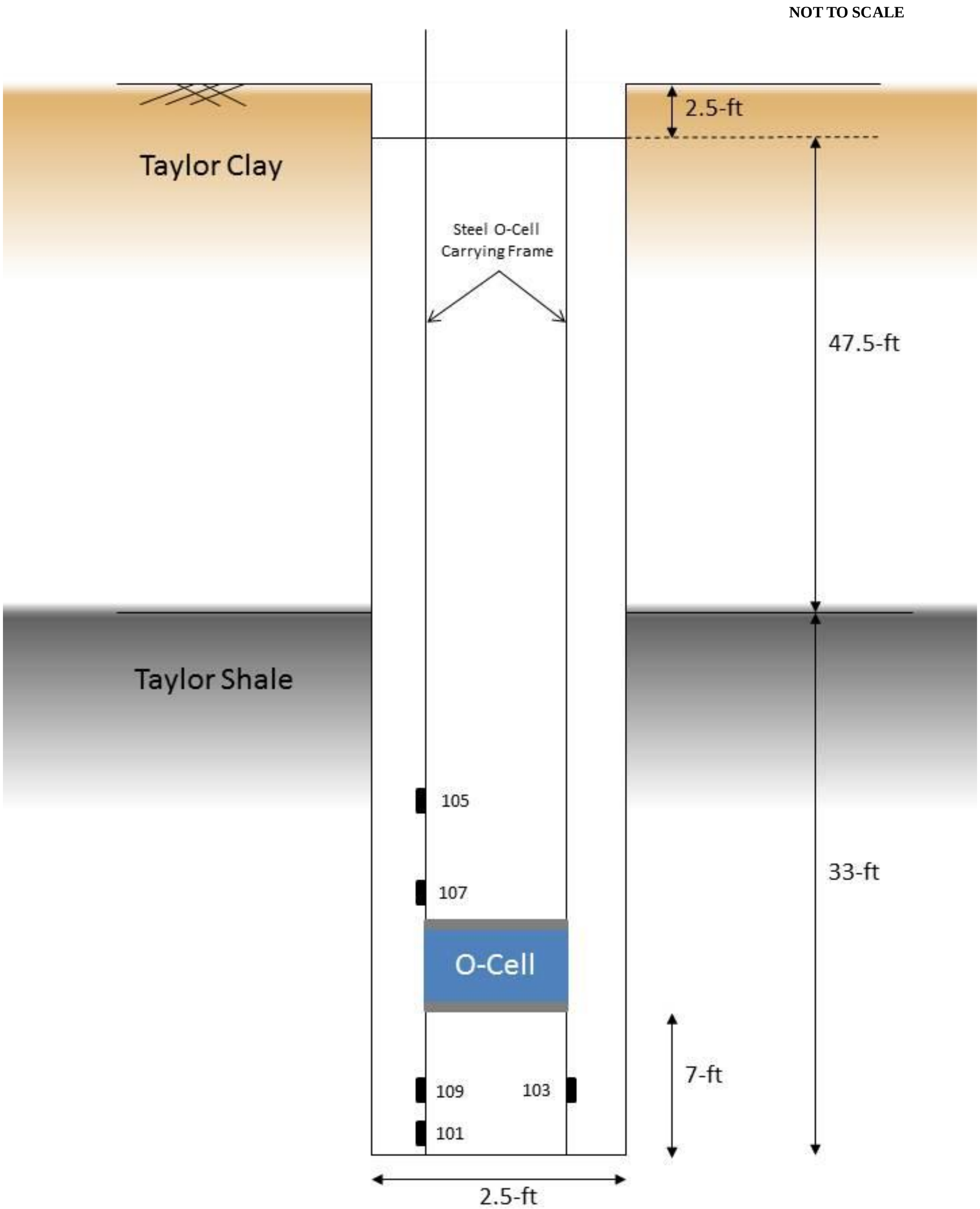


Figure 7.8: Test Shaft #1 As-Built

Table 7.1: As-Built Elevations and Depths for Test Shaft #1

	Elevation (ft)	Depth (ft)
Ground Surface	569.7	0.0
Top of Concrete	567.2	2.5
Top of Shale	519.7	50.0
S.G. 105	502.5	67.2
S.G. 107	469.9	72.8
Top of O-Cell™(1)	495.8	73.9
Bottom of O-Cell™(1)	494.1	75.6
S.G. 103/109	490.0	79.8
S.G. 101	488.1	81.6
Tip of Shaft	487.0	82.8

Note: (1)Refers to edge of the steel plate

7.1.2 Concrete Strength Testing

Five concrete cylinders were formed by a Fugro materials technician on the day of the concrete pour (August 24, 2012). The 28-day strength specification for the concrete used in TS #1 is 3,600-psi. A 7-in slump was measured on the concrete mix and the five cylinders were allowed to cure before being brought to the Fugro Construction Materials Testing (CMT) laboratory in Austin, Texas. Tests on the cylinders were run on days 6, 7, 28 (twice), and 56. A concrete cylinder was strength tested on day 6 (August 30, 2012); coinciding with the load test for TS #1. The concrete strength recorded on the day of the load test was 2,430-psi. The concrete strength report of TS #1 can be found in Appendix B.

7.1.3 SoniCaliper Profiling

A SoniCaliper, a cross-sectional profiling device, was lowered into the test shaft, prior to the concrete installation. The shaft caliper is lowered to the tip of the shaft and is brought up in 2-ft increments, recording sonar measurements for each increment. The measurements take a 360º sweep of the current depth, allowing the dimensions of the shaft to be plotted (Figure 7.9). The profile of the lowest cross section shows the shaft to be approximately 6-in off center, which can be attributed to the drill bit being pushed off center from inconsistencies in the soil. The shaft was calipered from 4- to 80-ft, with the results being presented in Appendix B.

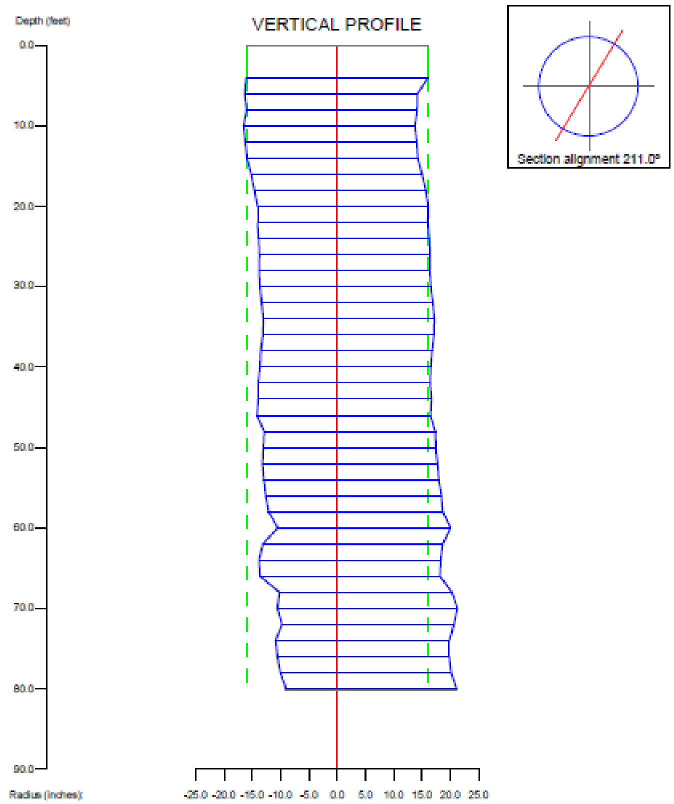


Figure 7.9: SoniCaliper Reading for Test Shaft #1 for Section Alignment: 211.0°

7.2 TEST SHAFT #2

7.2.1 Construction of Test Shaft

Test Shaft #2 (TS #2) was installed on September 11th and 12th, 2012. It was determined to place TS #2 between soldier piles No. 51 and No. 52 of RWE. The center of the drilled shaft was also placed 15.5-ft from the centerline of RWE. McKinney drilled the 30-in shaft by means of the dry method without a casing on September 11th and continued until a depth of about 80-ft was reached. The base was visually inspected and a weighted tape was lowered to confirm the final depth. Again, no water table was detected throughout the entire depth of drilling. Drilling was then stopped while the O-Cell™ frame was assembled.

For TS #2, the O-Cell™ was installed at a depth of 70-ft below grade (10-ft above the tip of the shaft). Therefore, an 80-ft carrying frame was constructed that spanned the entire upper drilled shaft along with a 10-ft lower carrying frame. For TS #2, the strain gauge attachments were modified from the previous installation in order to prevent damage and loss of the instrument. Therefore, steel brackets containing fabricated holes were welded to a cross brace on the carrying frame. The gauges were put through the holes of the bracket and fastened down, as shown in Figure 7.10. For this shaft installation, only 2 gauges out 14 were unresponsive. Once again, it is assumed that the affected gauges were affected by the concrete installation. Those gauges are shown on the Loadtest Report in Appendix C, but not discussed further. The final assembly was then lifted by McKinney in preparation to be lowered into the hole (Figure 7.11).

Following the O-Cell™ assembly, the preliminary concrete pour took place. The concrete was poured via free-falling until the field crew measured just over 10-ft of concrete in the hole. The O-Cell™ frame was then lowered into the hole, pushing the lower frame (equipped with strain gauges) into the pre-poured concrete. Once in place, the remaining concrete was added to the hole, leaving about 2-ft of space between the top of shaft and the ground surface. The final as-built diagram for Test Shaft #2 is shown in Figure 7.12, with elevations and depths of interest presented in Table 7.2.

Figure 7.10: Strain Gauges 205 & 208 Fastened to the Carrying Frame of Test Shaft #2

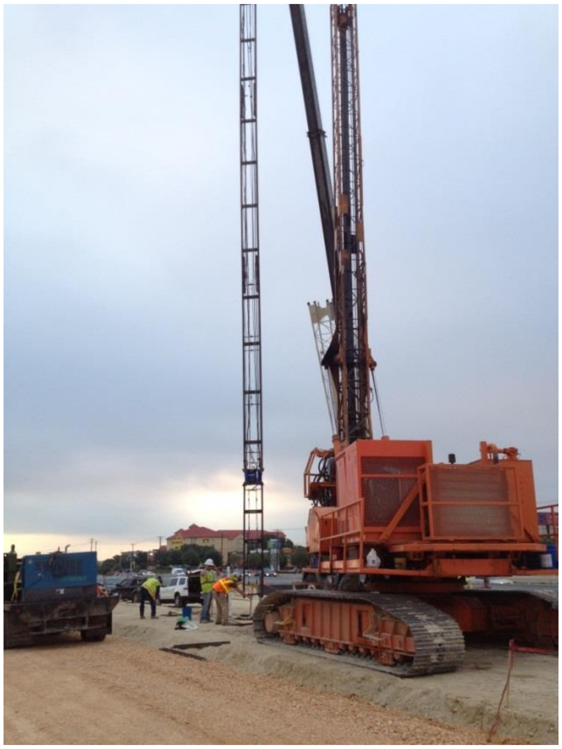


Figure 7.11: Final Assembly of the Carrying Frame for Test Shaft #2

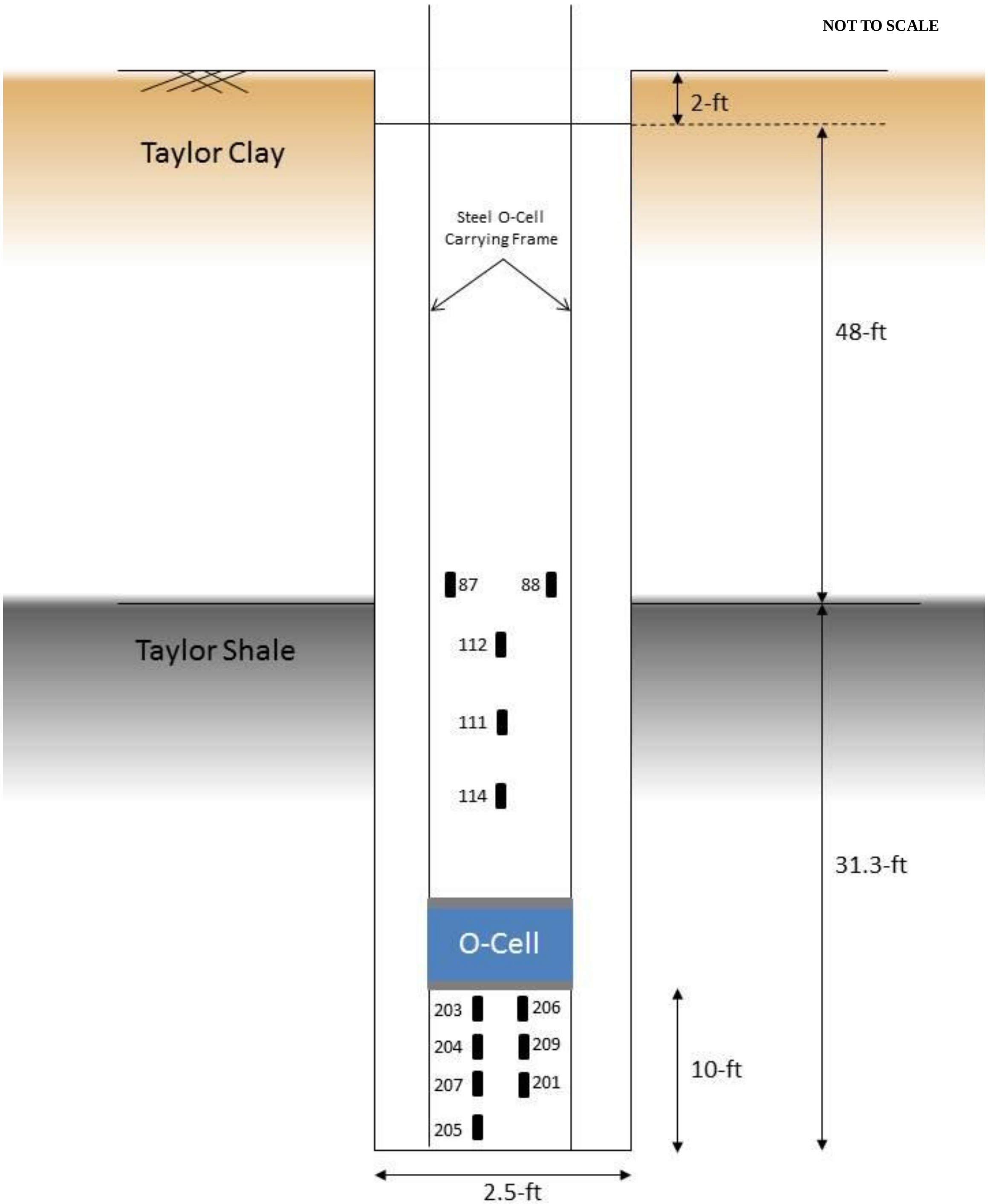


Figure 7.12: Test Shaft #2 As-Built

Table 7.2: As-Built Elevations and Depths for Test Shaft #2

	Elevation (ft)	Depth (ft)
Ground Surface	569.7	0.0
Top of Concrete	567.7	2.0
S.G. 87/88	521.2	48.5
Top of Shale	519.7	50.0
S.G. 112	518.5	51.2
S.G. 111	512.2	57.5
S.G. 114	507.0	62.7
Top of O-Cell™(1)	499.9	69.8
Bottom of O-Cell™(1)	498.3	71.5
S.G. 203/206	497.1	72.6
S.G. 204/209	494.4	75.3
S.G. 207/201	492.4	77.3
S.G 205	489.8	79.9
Tip of Shaft	488.5	81.3
Note: (1)Refers to edge of the steel plate		

7.2.2 Concrete Strength Testing

Five concrete cylinders were formed on the day of the concrete pour (September 12, 2012). The 28-day strength specification for the concrete used in TS #2 is 4,500-psi; a higher strength than that of TS #1. A 9.5-in slump was measured on the concrete mix and the five cylinders were allowed to cure before being brought to the Fugro CMT laboratory. Tests on the cylinders were run on days 7, 9, 28 (twice), and 56. The strength test run on day 9 (September 21, 2012) coincided with the load test for TS #2. The concrete strength recorded on the day of the load test was 3,490-psi. The concrete strength report for TS #2 can be found in Appendix C.

7.2.3 SoniCaliper Profiling

A SoniCaliper was also lowered into the second test shaft, prior to the concrete pour. At 78-ft below the ground surface, the caliper shows that Test Shaft #2 is approximately 8-in off of the true vertical datum (green dotted line) as shown in Figure 7.13. The shaft was calipered from 6- to 78-ft and the results are presented in Appendix C.

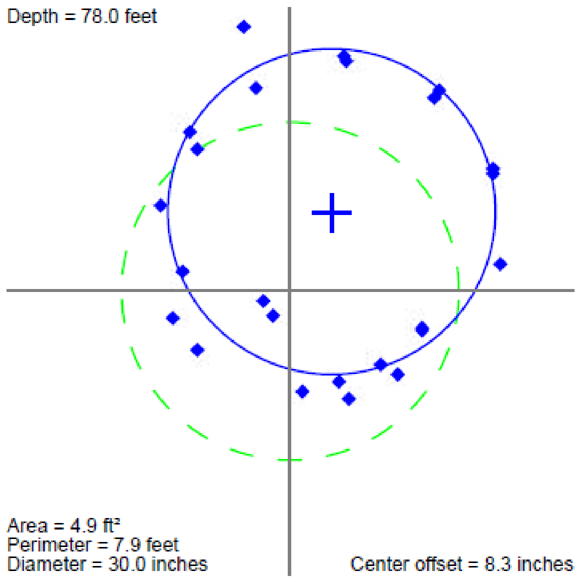


Figure 7.13: Cross-Section of Test Shaft #2 at 78-ft Below the Ground Surface using the SoniCaliper

Chapter 8: O-Cell™ Test Results

8.1 Test Shaft #1 Results

The load-displacement relationship for Test Shaft #1 is shown in Figure 8.1. The O-Cell™ applied load at about 113-kip increments (corresponding to an increase of 500-psi within the O-Cell™), up to a load of 681-kips ($Q_{allowable}$ = 662-kips from the TxDOT design method) for the initial loading cycle. The loading was then dropped in four equal increments to 60-kips. The loading was brought back to the 681-kips and increased again in 113-kip increments until the maximum stroke of the O-Cell™ was reached and the rock socket was plunged.

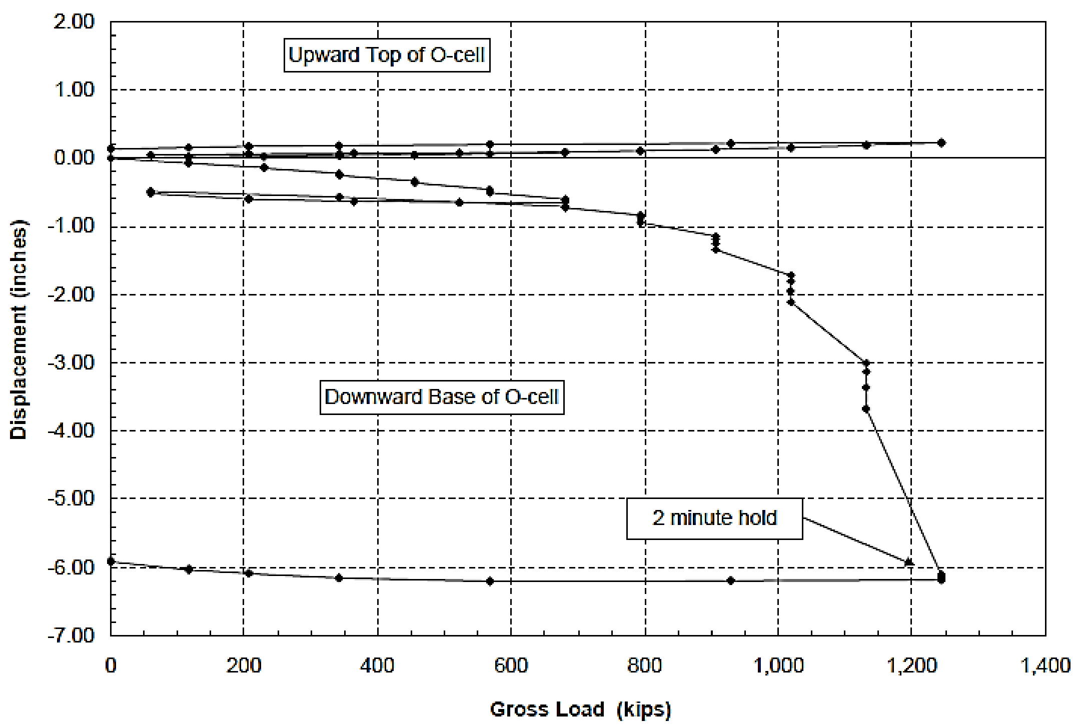


Figure 8.1: Measured Load-Displacement Plot for Test Shaft #1

The top-loaded load-settlement curve for Test Shaft #1 is presented in Figure 8.2. The thin line represents the movement of measured data for a "rigid" shaft. The maximum settlement plotted for the rigid shaft corresponds to the maximum top of O-Cell™ displacement; 0.2-in. The thick line represents the shaft movement while considering the additional elastic compression as discussed in Section 6.2.

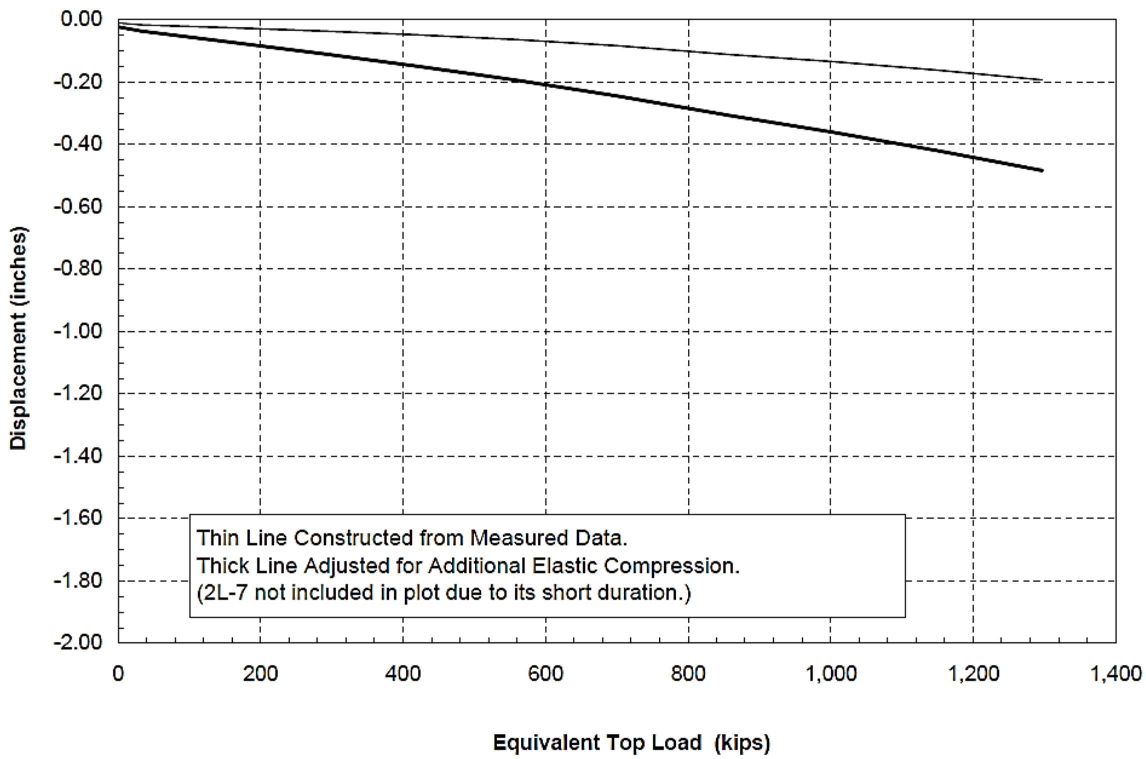


Figure 8.2: Equivalent Top-Loaded Load-Settlement Curve for Test Shaft #1

During loading, the shaft movements were recorded at the 4- and 8-minute intervals, allowing the apparent creep to be determined. The 4- to 8-minute displacement is plotted against the net load in Figure 8.3; demonstrating that no apparent creep was observed in the shaft above the O-Cell™ in Test Shaft #1. The maximum creep recorded in the upper shaft was about 0.004-inches. An apparent creep limit occurred at about 690-kips for the shaft below the O-Cell™, shown in Figure 8.4. A displacement of about 0.32-inches was recorded at the last creep interval, just prior to plunging.

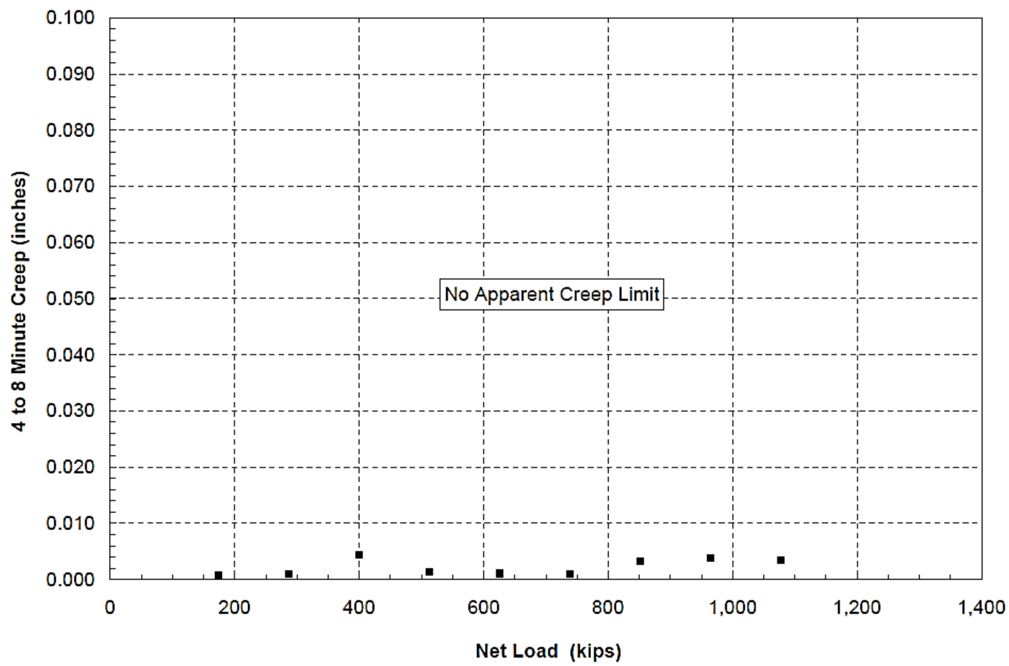


Figure 8.3: Upper Side Shear Creep Limit above the O-Cell™ in Test Shaft #1

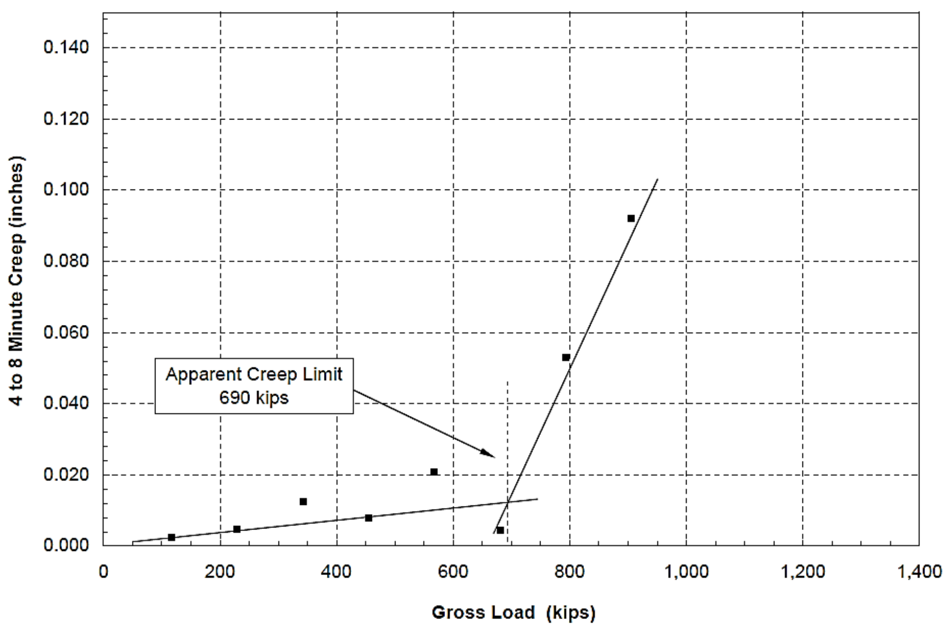


Figure 8.4: Lower Side Shear and Base Creep Limit for Shaft below the O-Cell™ in Test Shaft #1

Figure 8.5 presents the loading distribution throughout Test Shaft #1. The load calculated at each strain gauge level was computed using the method discussed in Section 6.4. It should be noted that the difference in loads shown immediately above and below the O-Cell™ are different. The load applied upwards by the O-Cell™ is considered a "net" loading; the buoyant weight of the upper shaft is subtracted from the load applied by the O-Cell™. The load applied to the lower shaft is the gross load applied from the O-Cell™. The load distribution for Test Shaft #2 was calculated in the same manner (Figure 8.13). The loading and strain gauge data measured during the load test of Test Shaft #1 is included in Appendix B. Assumptions made for the required calculations include the following:

- The elasticity of the shaft was estimated by Eq. 6.1, using the compressive strength (f_c') of the shaft recorded on the day of the testing (i.e. 6-day compressive strength for Test Shaft #1),
- A uniform load is distributed throughout the entire cross-section of the pile at all elevations,
- The entire length of the test shaft has a diameter of 30-in (consistent with the SoniCaliper data).

With those assumptions in mind, strain gauge 107 was excluded from the analysis due to the gauge being placed too close to the load cell. The load in this area seemed to be distributed over a diameter smaller than 30-in, therefore providing loads higher than anticipated.

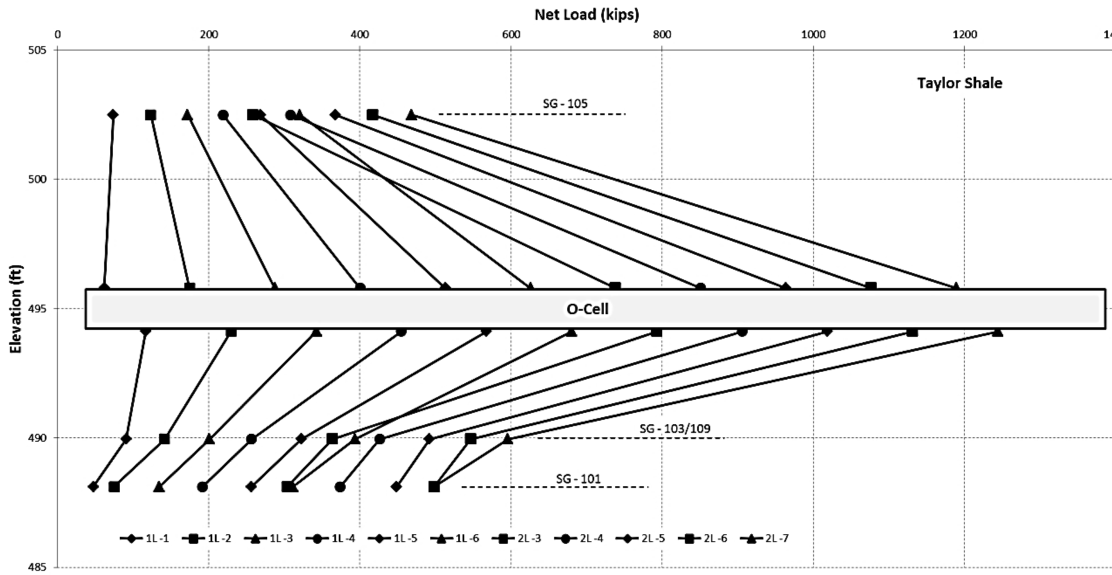


Figure 8.5: Axial Load Distribution for Test Shaft #1

The t-z curves for the shaft-shale interaction were calculated using the method discussed in Section 6.4. Figure 8.6 displays the mobilized unit side shear with respect to displacement for the portion of the shaft above to O-Cell™ in Test Shaft #1. The mobilized unit side shear curve continually increases for the full displacement of the top of the O-Cell™ (0.23-in); indicating the ultimate value of mobilized shear strength was not reached. Figure 8.7 displays the mobilized unit shear information for the rock socket below the O-Cell™. The area closest to the O-Cell™ of the lower shaft (O-Cell™ to S.G. 103/109) reached a maximum mobilized shear strength between about 15- to 20-ksf, whereas, the lower portion of the shaft (S.G. 103/109 to S.G. 101) had a maximum mobilized shear strength of about 5-ksf.

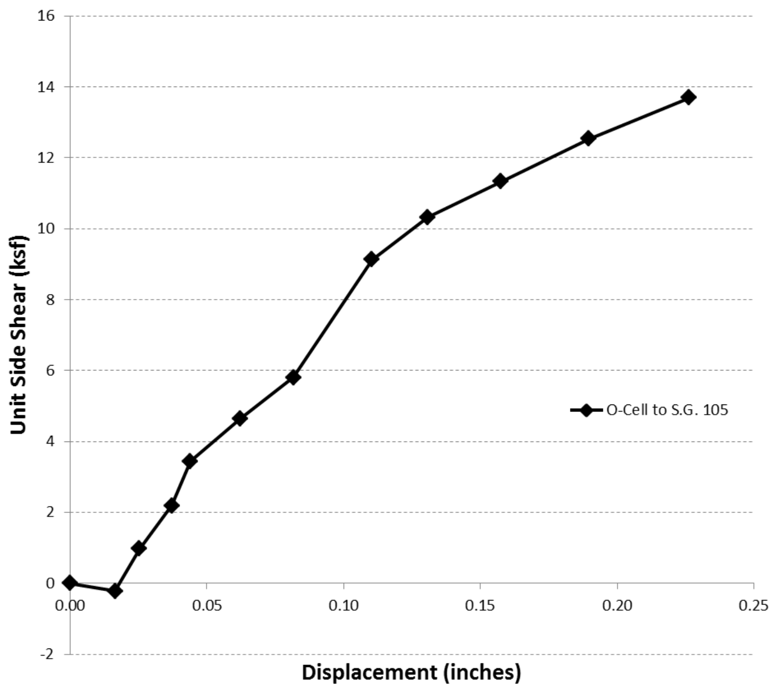


Figure 8.6: Unit Side Shear vs. Displacement above the O-Cell™ of Test Shaft #1

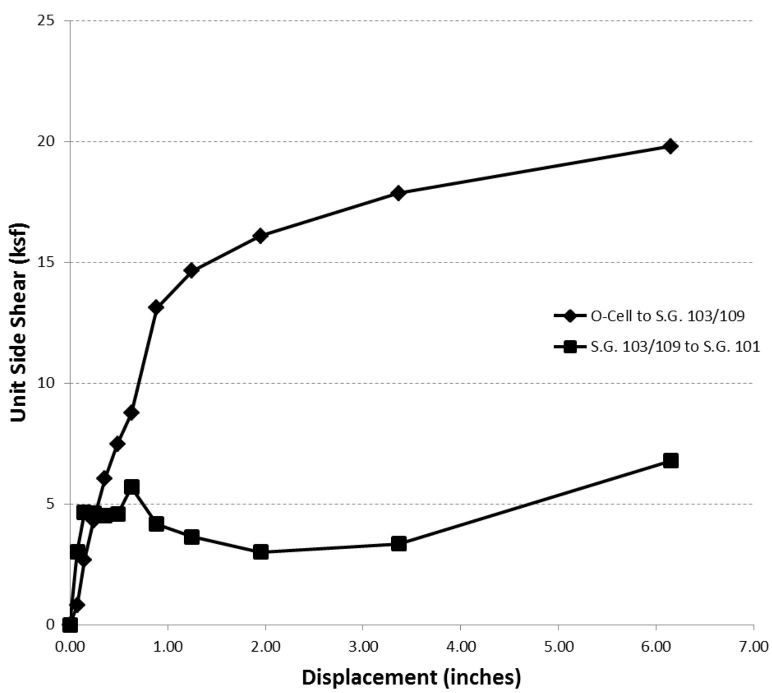


Figure 8.7: Unit Side Shear vs. Displacement below the O-Cell™ of Test Shaft #1

The mobilized unit end bearing for Test Shaft #1 is presented in Figure 8.8. The end bearing was calculated using S.G. 101, located about 1-ft above the tip of the shaft. The strains recorded from the strain gauge were converted to kips, using the approach discussed in Section 6.4. The load was then converted to ksf, by factoring in the cross-sectional area of the base. The end bearing reached a maximum value of just over 100 ksf when fully mobilized.

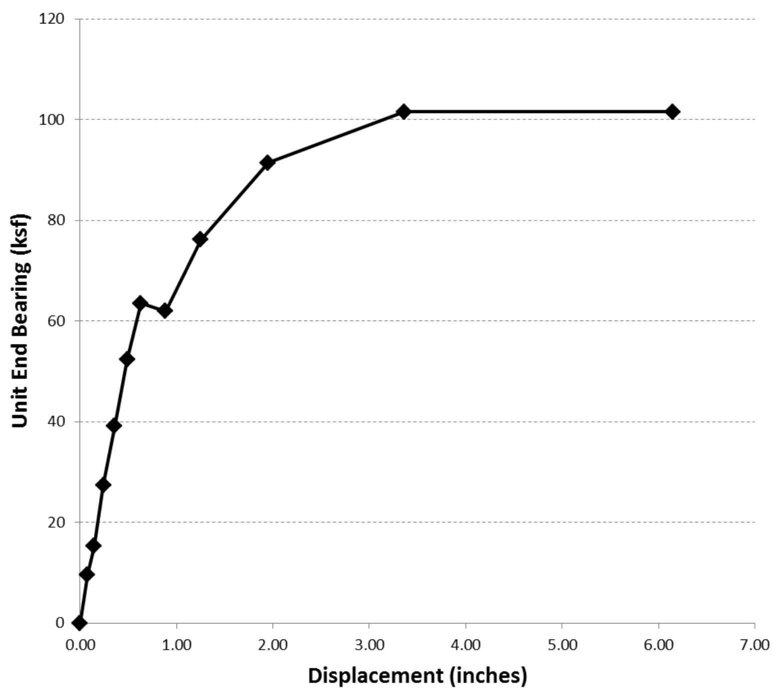


Figure 8.8: Unit End Bearing vs. Displacement in Test Shaft #1

8.2 TEST SHAFT #2 RESULTS

The load-displacement relationship for Test Shaft #2 is shown in Figure 8.9. The O-Cell™ was loaded at about 113-kip increments, up to a load of 904-kips ($Q_{allowable}$ = 815-kips from the TxDOT design method) for the initial loading cycle. The loading was then dropped in four equal increments to 60-kips. The load was increased back to the 904-kips during the reload cycle. Although more capacity was predicted for Test Shaft

#2 (due to the extra 3-ft of length), the load was increased to 1,107-kips where plunging occurred.

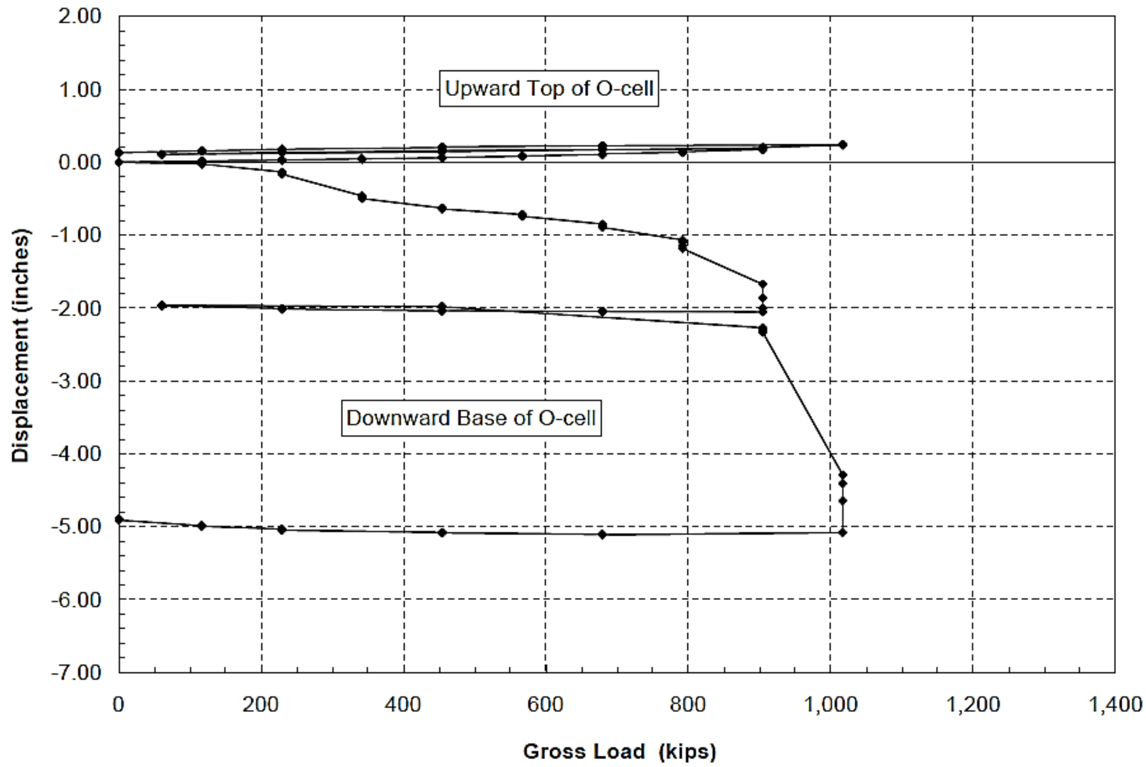


Figure 8.9: Measured Load-Displacement Plot for Test Shaft #2

The top-loaded load-settlement curve for Test Shaft #2 is presented in Figure 8.10. The curve was constructed using the measured data up to a displacement of 0.24-in; the maximum displacement of the top of the O-Cell™. The "rigid" curve was adjusted for additional elastic displacement, represented by the thick line in the figure.

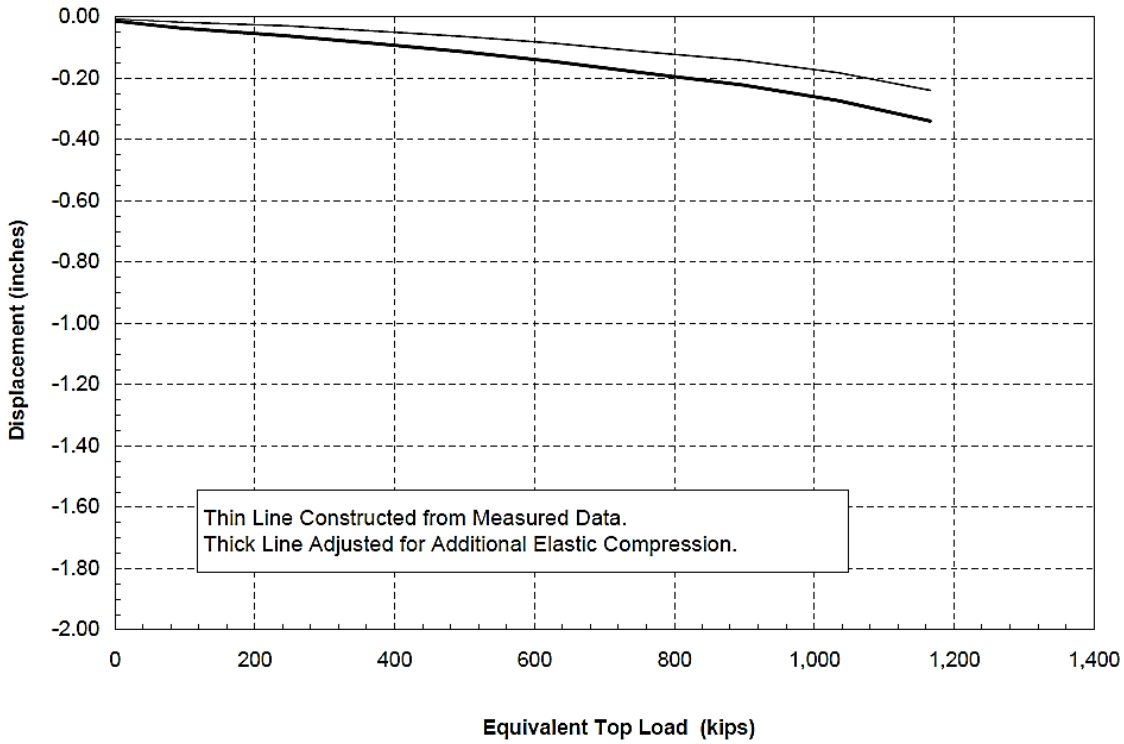


Figure 8.10: Equivalent Top-Loaded Load-Settlement Curve for Test Shaft #2

Figure 8.11 shows the 4- to 8-minute creep recorded against load, demonstrating that no apparent creep was observed in the shaft above the O-Cell™ in Test Shaft #2. The maximum creep recorded in the upper shaft was about 0.005-inches. An apparent creep limit occurred at about 720-kips for the shaft below the O-Cell™, shown in Figure 8.12. A displacement of about 0.14-inches was recorded at the last creep interval, just prior to plunging.

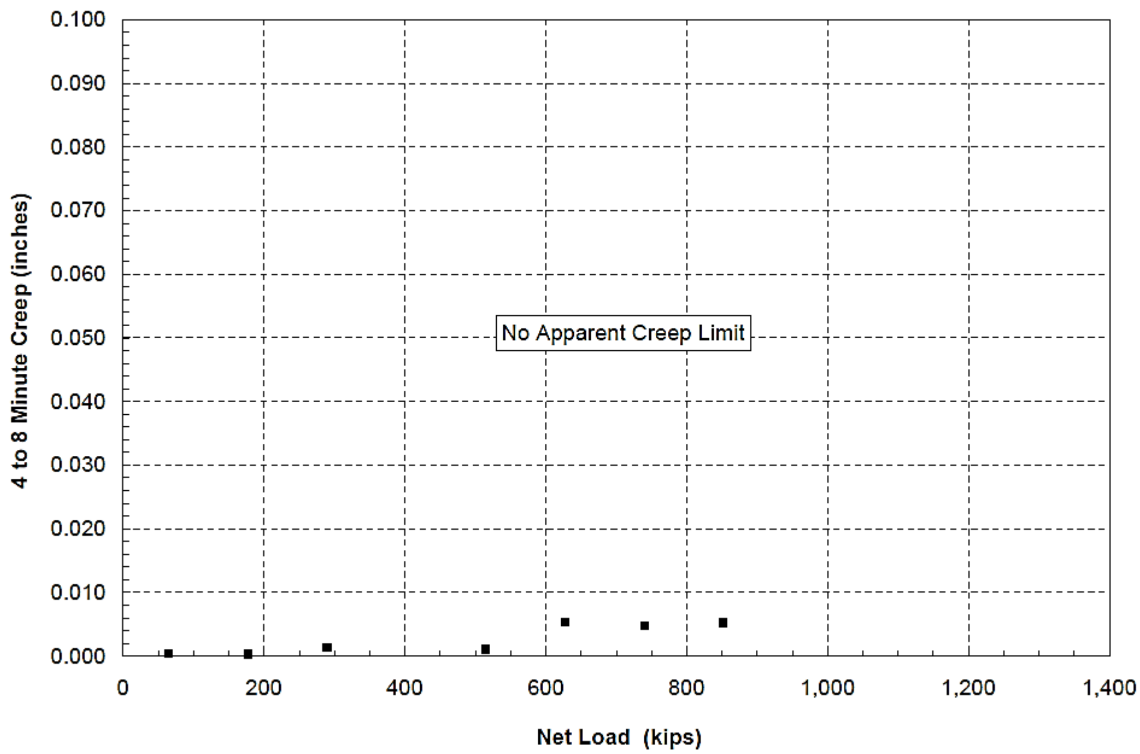


Figure 8.11: Upper Side Shear Creep Limit above the O-Cell™ in Test Shaft #2

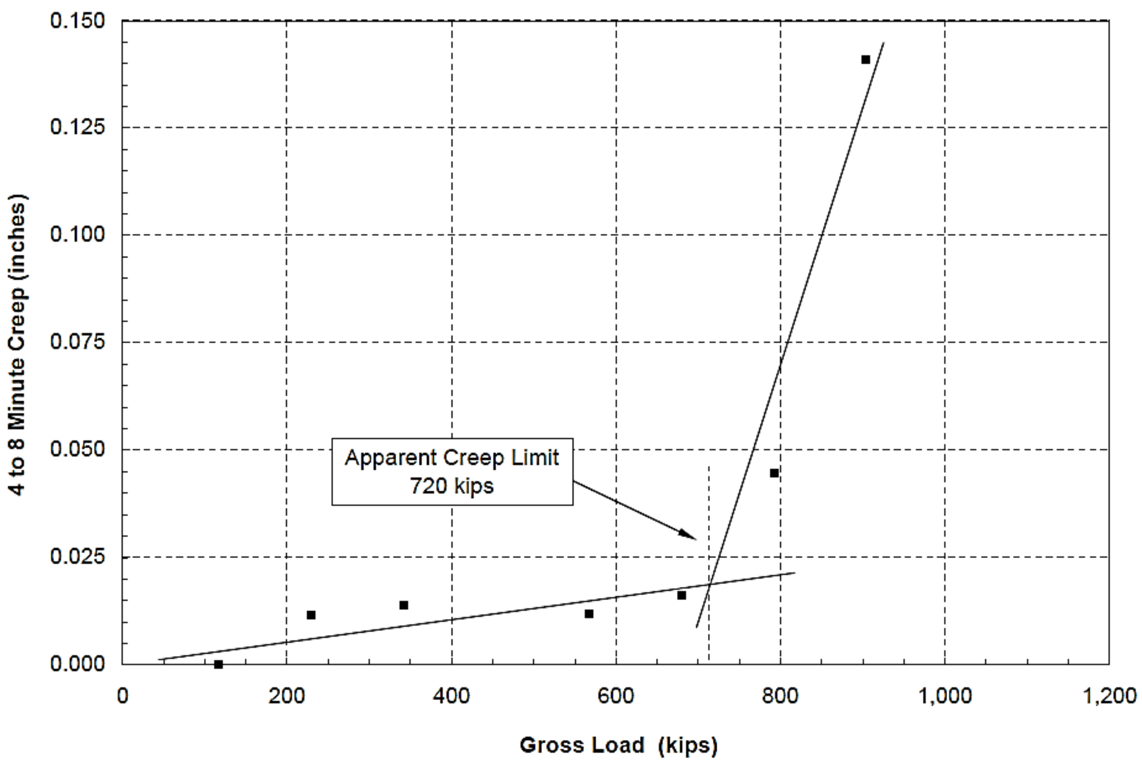


Figure 8.12: Lower Side Shear and Base Creep Limit for Shaft below the O-Cell™ in Test Shaft #2

The axial load distribution for Test Shaft #2 is presented in Figure 8.13. The loads reported were calculated in the same manner as Test Shaft #1, with the same assumptions. The elasticity of the shaft was estimated using the compressive strength of the concrete recorded on the day of the load testing (concrete cylinder with 9-days of curing). The loading and strain gauge data for the load test of Test Shaft #2 is included in Appendix C.

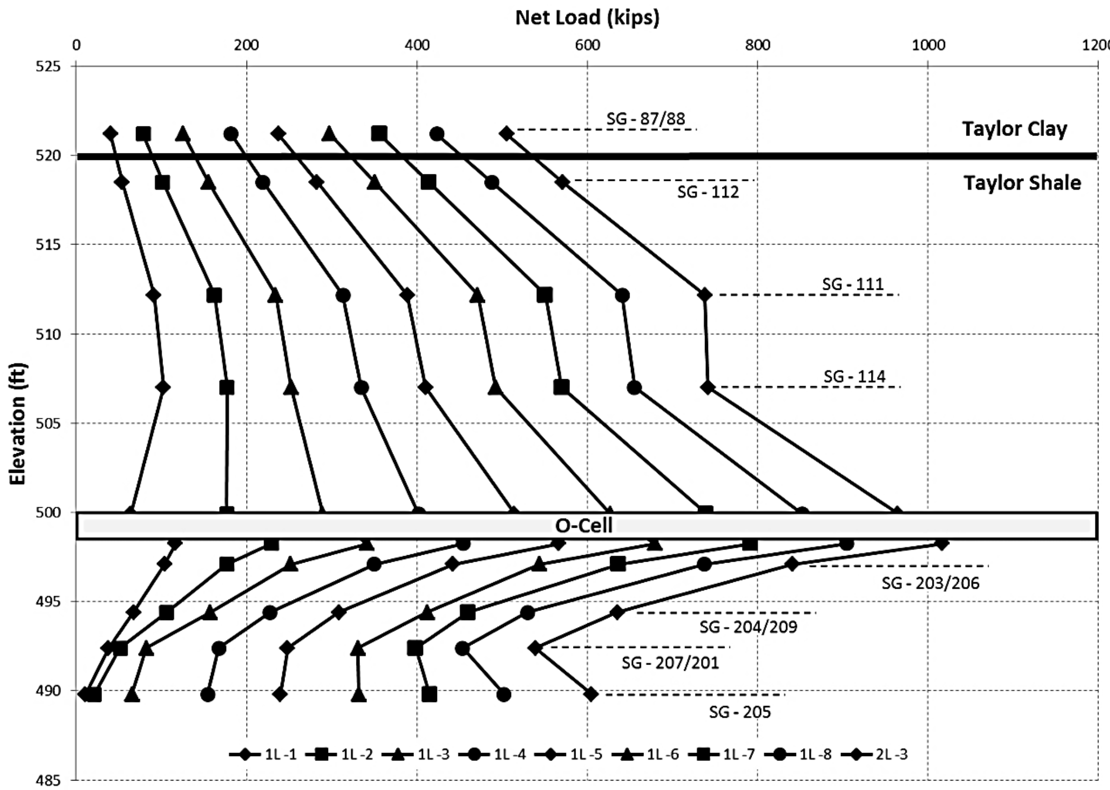


Figure 8.13: Axial Load Distribution for Test Shaft #2

The t-z curves for Test Shaft #2 are presented in Figure 8.14 and Figure 8.15. The mobilized t-z curves (Figure 8.14), for three of the four upper shaft sections, increase continually during the entirety of the loading, indicating that a maximum value of mobilized unit shear strength was not obtained. The area of the shaft between S.G. 114 to S.G. 111 reached an ultimate mobilized shear strength value of about 0.5-ksf, much lower than the other areas measured. The mobilized unit shear information for the rock socket below the O-Cell™ is presented in Figure 8.15. The maximum values of mobilized shear strength are greatest closest to the loading zone, while gradually decreasing as the measurements approach the shaft tip. This is trend is similar to the measurements found in the lower shaft of Test Shaft #1.

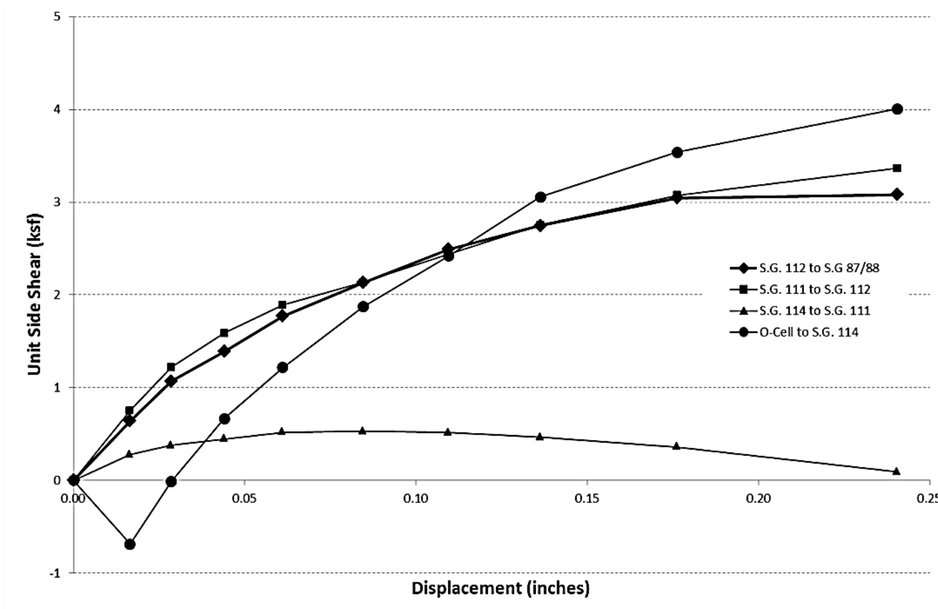


Figure 8.14: Unit Side Shear vs. Displacement above the O-Cell™ of Test Shaft #2

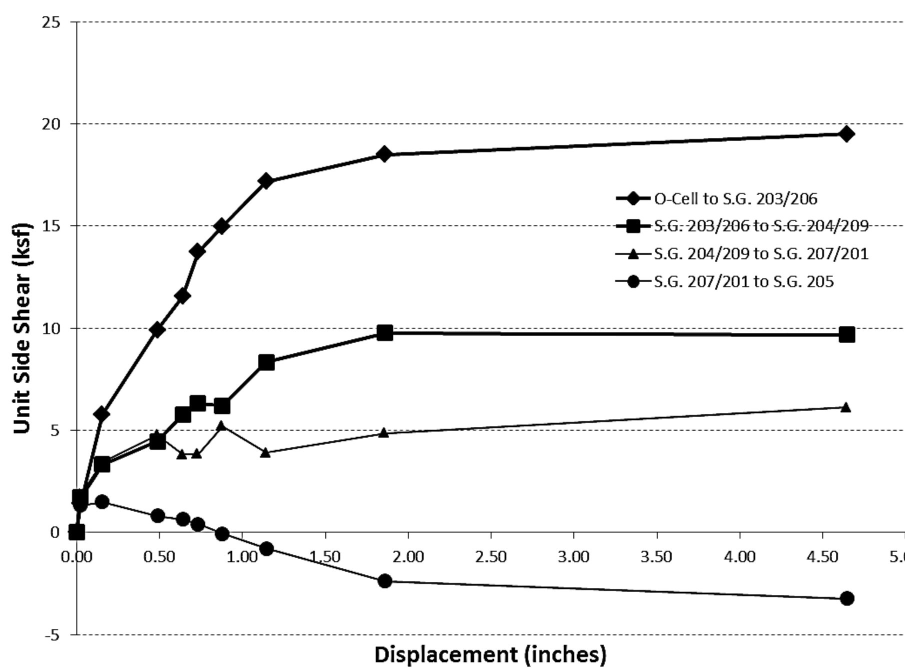


Figure 8.15: Unit Side Shear vs. Displacement below the O-Cell™ of Test Shaft #2

Figure 8.16 displays the mobilized unit end bearing for Test Shaft #2, as measured using the strains acquired from S.G. 205. This strain gauge was located about 1-ft from the tip and the strains were converted to kips in the same manner as previously discussed. The end bearing reached a maximum between 100- and 120-ksf during testing.

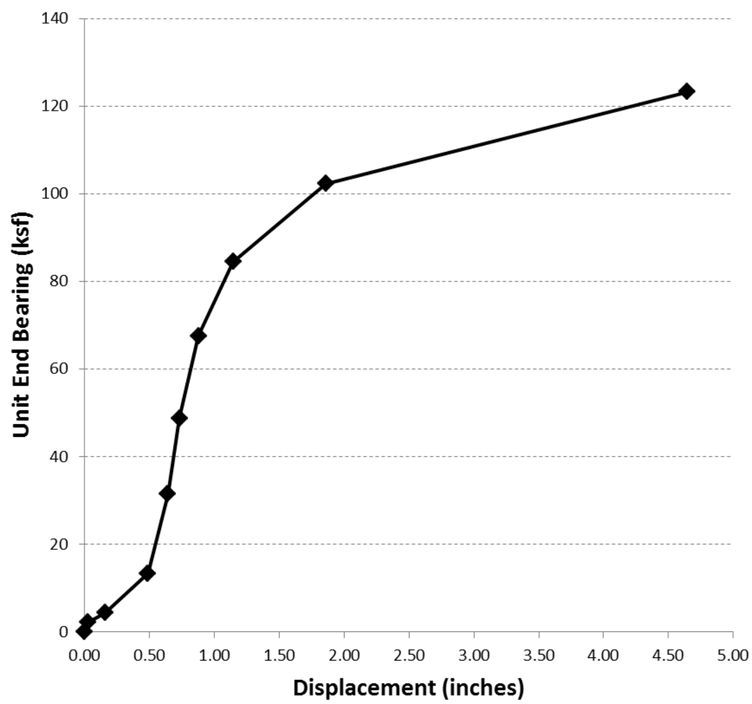


Figure 8.16: Unit End Bearing vs. Displacement in Test Shaft #2

Chapter 9: Analysis of Results

This section discusses the applicability of the current design methods to the measured data, along with comparisons from similar previous studies. Further analysis of the measured ultimate loads on each test shaft will involve the predicted unit resistances (side resistance and end bearing) as shown below in Table 9.1. Ultimate values were calculated using the TxDOT design method by removing the factors of safety applied to the charts discussed in Section 3.1. A range of nominal values was calculated using the FHWA method, once again due to the high variation of values resulting from the unconfined compressive testing. The q_u values (7- and 20-tsf) used to calculate the range of resistances were the minimum and maximum values measured from compressive strength tests performed on the Taylor Shale.

Table 9.1: Predicted Unit Resistances for TxDOT and FHWA Methods

Method	Unit Side Shear	Unit End Bearing
TxDOT TCP = $\frac{1.5"}{100\text{ blows}}$	20-ksf	124-ksf
FHWA q_u = 7-tsf to 20-tsf	2-ksf to 7-ksf	35-ksf to 100-ksf

9.1 End Bearing

The measured ultimate unit end bearing values ranged from 100- to about 120-ksf for Test Shafts #1 and #2, respectively, at large displacements. The predicted values of unit side shear from the TxDOT (ultimate value) and FHWA (nominal value) design methods, shown in Table 9.1, are superimposed on the q-z curves in Figure 9.1. The maximum values of the measured q-z curves fall below the TxDOT design method and above the upper bound estimate from the FHWA method.

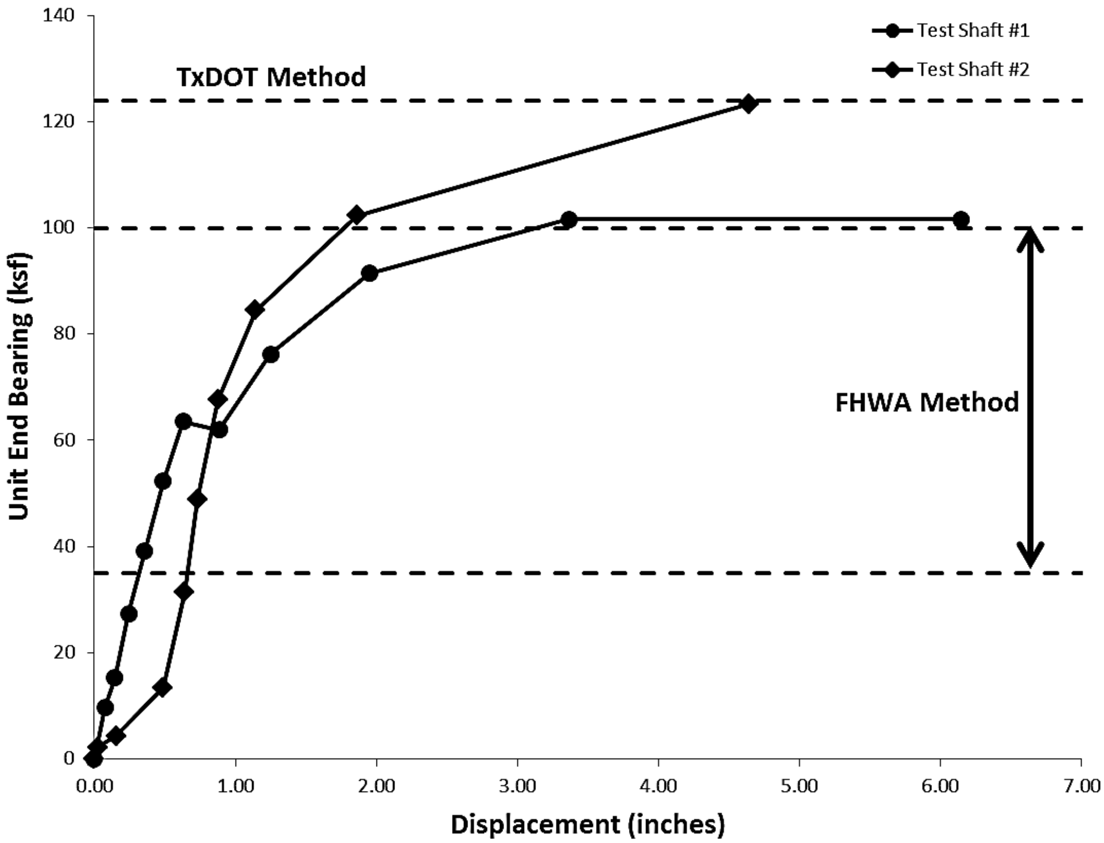


Figure 9.1: Q-Z Curves for Test Shafts #1 & #2 in Relation to the Predicted Capacities from the TxDOT and FHWA Design Methods

O'Neill and Reese (1998) estimated the end bearing (and side load transfer) vs. displacement, with the end bearing normalized by the estimated ultimate end bearing and the displacement normalized by the diameter of the shaft, as shown in Figure 9.2. The estimated maximum unit end bearing predicited by the FHWA design method ($q_{BN,max}$ =100-ksf for q_u=20-tsf) was used with the estimated q-z curves from O'Neill and Reese (1988) and plotted alongside the q-z curves developed from the test shafts (Figure 9.3). The estimated q-z curves reach a maximum mobilized end bearing at smaller displacements than the q-z curves measured in this study, although the estimated lower bound curve matches the measured data fairly well. Also plotted on the figure are the measured q-z curves from shafts MT1, MT2, and MT3; performed in the Taylor Shale near the site of this study (Aurora and Reese, 1976).

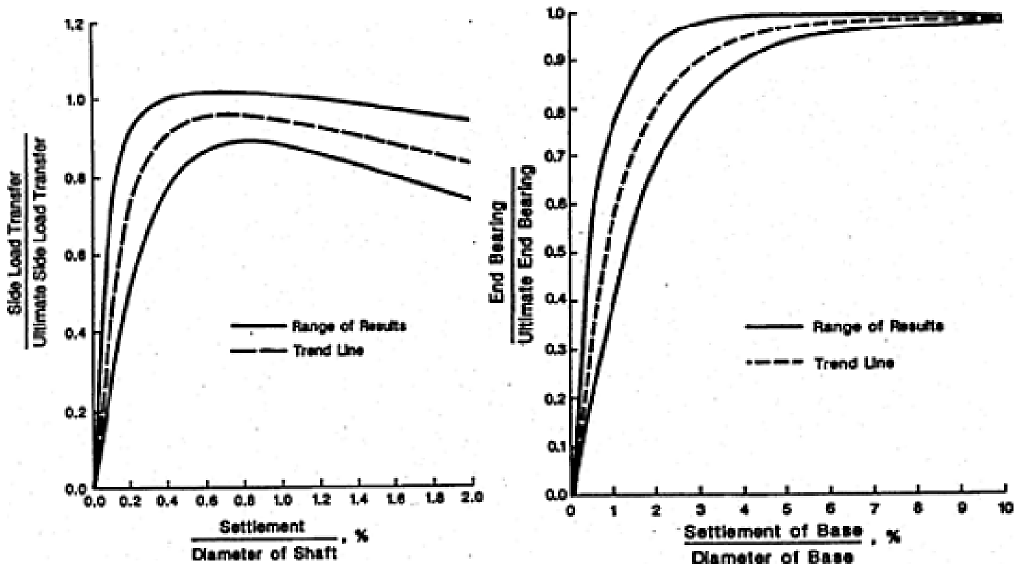


Figure 9.2: Normalized Load-Displacement Relationships (O'Neill and Reese, 1988)

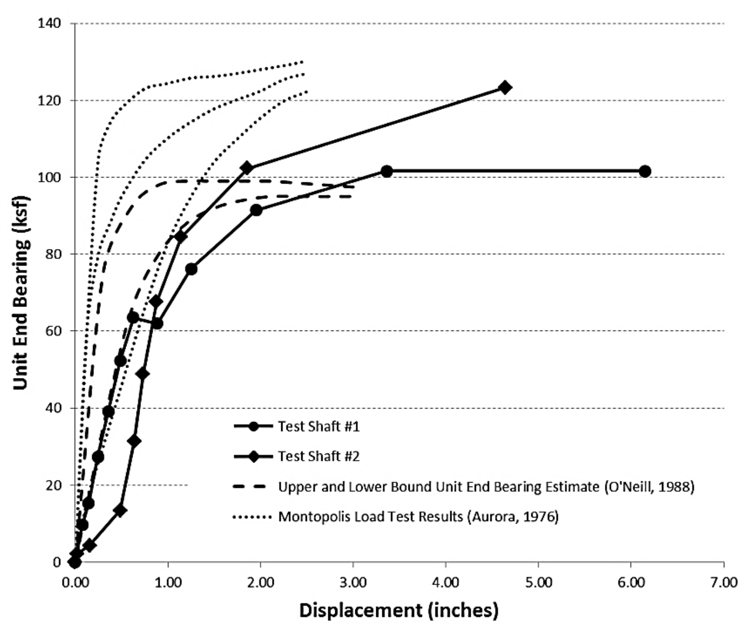


Figure 9.3: Q-Z Curves in Relation to Estimate of Unit End Bearing from O'Neill and Reese (1988) and Measured Q-Z Curves from Shafts MT1, MT2, and MT3 (Aurora and Reese, 1976)

Table 9.2 displays the unit end bearing values taken at an axial displacement of 5% of the shaft diameter ($q_{p, 5\%D}$), as well as the ultimate values achieved during the load tests. The ultimate values are defined as the maximum unit end bearing value recorded. The ultimate unit end bearing values are plotted in relation to the current TxDOT design curve in Figure 9.4. The figure also includes the unit end bearing for the Montopolis load tests (discussed in Section 2.3), which defined the failure unit end bearing at 5%*D (1.5-in) of tip movement, thus, not ultimate values. The significance of the Montopolis results to this study is the nearby location of the tests, as well as the similarity in TCP blow counts at the tip of the shafts (TCP values: 1.5-in per 100 blows). Figure 9.4 also includes the O-Cell™ test results from Pierce et al. (2012) that were placed in shale in Missouri, along with the developed end bearing relationship. In addition, the end bearing results and the developed correlation from the three load tests in Dallas, Texas (Nam and Vipulanandan, 2010) are also plotted. It should be noted that the measured end bearing value from the Dallas O-Cell™ tests, having a TCP value harder than 1-in per 100 blows, was performed in limestone. The circled symbols in the figure represent ultimate values measured from the respective load tests.

Table 9.2: Measured Ultimate End Bearing Values

	$q_{p, 5\%D}$ (ksf)	$q_{p, ult}$ (ksf)
Test Shaft #1	83	102
Test Shaft #2	95	123

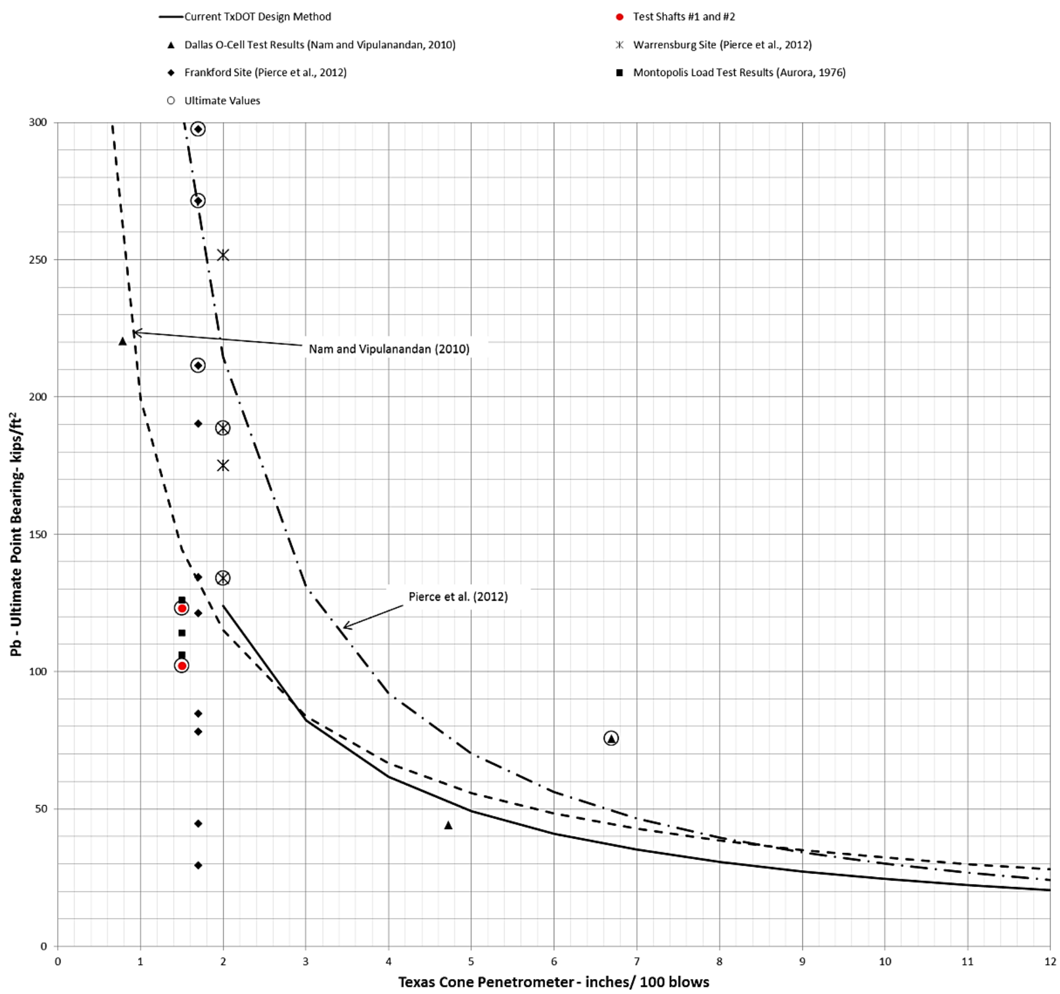


Figure 9.4: Ultimate Point Bearing (ksf) in relation to TxDOT Design Method (TxDOT, 2006), Dallas O-Cell Research Test Results (Nam and Vipulanandan, 2010), Missouri O-Cell Research Test Results (Pierce et al., 2012), and Montopolis Load Test Results (Aurora and Reese, 1976)

9.2 SIDE RESISTANCE

The measured ultimate unit side shear values ranged from 0- to 20-ksf for the lower sections of Test Shafts #1 and #2. The predicted values of ultimate unit side shear from the TxDOT and FHWA design methods, shown in Table 9.1, are superimposed on the t-z curves for the lower sections of the test shafts in Figure 9.5. The two t-z curves maximizing near the ultimate value of the TxDOT design method (20-ksf) are measured within the area between the O-Cell™ and the first strain gauge level of each shaft. As depicted in the plot, the ultimate unit shear strength tends to decrease as the zone of interest nears the tip of the shafts. Figure 9.6 better portrays this trend, with the distance from the tip from which each t-z curve is produced; *3.4D - 3.9D* represents the unit shear strength measured from the strain difference recorded between 3.4- to 3.9-diameters from the tip. The peak unit side resistance decreases dramatically approaching the tip of the shaft, especially within about one shaft diameter of the tip.

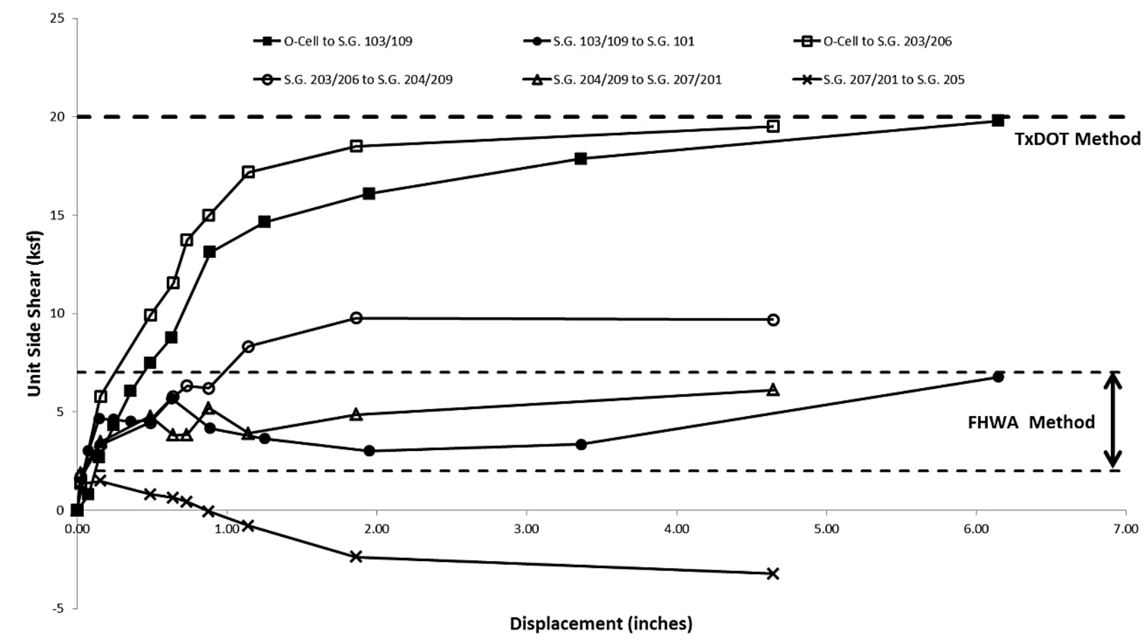


Figure 9.5: T-Z Curves for Test Shafts 1 & 2 in Relation to the Predicted Capacities from the TxDOT and FHWA Design Methods

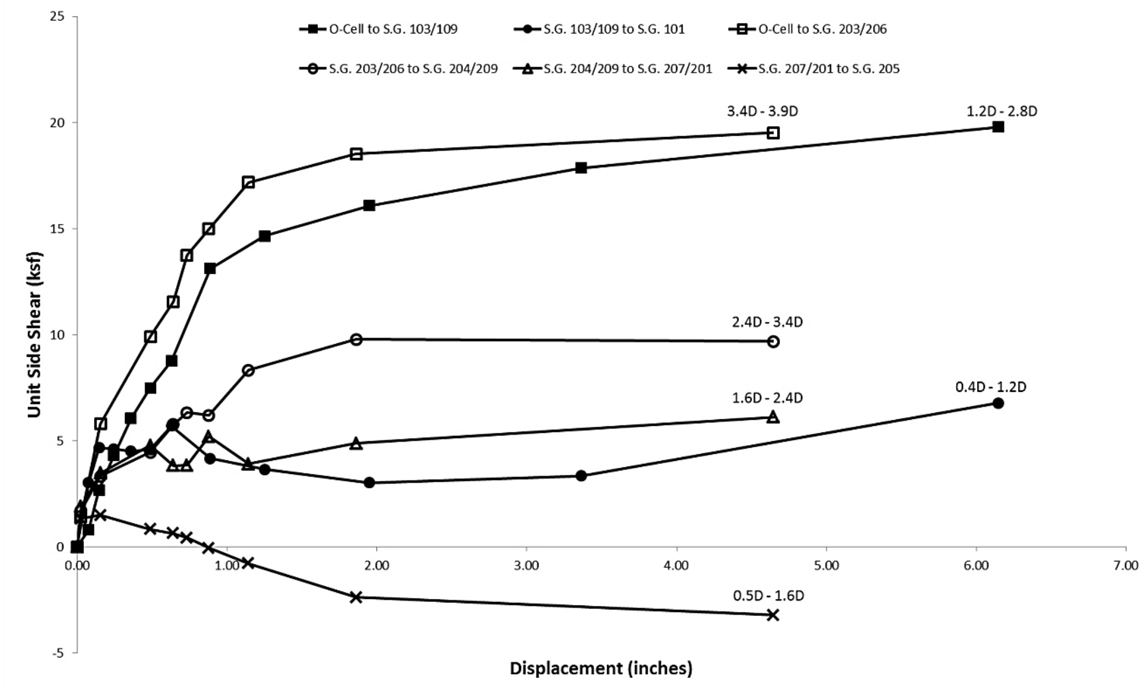


Figure 9.6: Lower Shaft T-Z Curves in Relation to Distance from Tip of Shaft (Normalized by Diameter)

Table 9.3 shows the ultimate side shear values taken from the t-z curves of the lower portions of the test shafts, in relation to the location from the shaft tip, normalized by the shaft diameter.

Table 9.3: Measured Values of Ultimate Side Shear

	Measurement Zone	$f_{s, max}$ (ksf)	Distance from Tip / Diameter of Shaft
Test Shaft #1	O-Cell™ to S.G. 103/109	19.8	1.2 to 2.8
	S.G. 103/109 to S.G. 101	6.8	0.4 to 1.2
Test Shaft #2	O-Cell™ to S.G. 203/206	19.5	3.4 to 3.9
	S.G. 203/206 to S.G. 204/209	9.6	2.4 to 3.4
	S.G. 204/209 to S.G. 207/201	6.1	1.6 to 2.4
	S.G. 207/201 to S.G. 205	1.5	0.5 to 1.6

Predicted t-z curves from O'Neill and Reese (1988) are plotted alongside the q-z curves developed from the test shafts (Figure 9.7). The side load transfer is normalized by the estimated ultimate unit side shear, predicited by the FHWA design method (conservative value of $f_{s,max}$=3.4-ksf for q_u=10-tsf), and is plotted alongside the t-z curves developed from the test shafts. Also shown in Figure 9.7 are the t-z curves within the Taylor Shale from shaft MT3; the shaft was performed in close vicinity to the test shafts of this study and installed in a similar manner (Aurora and Reese, 1976). The plot has been zoomed in to see a more detailed relationship between the t-z curves and the estimate of unit side shear. The predicted side load transfer mimics the increase in side shear with displacement measured in the test shafts for the curves that reached an ultimate shear strength close to that used in the prediction (3.4-ksf). The t-z curves closest to the O-Cell™ follow the predicted t-z relationships at low displacements, then proceed to the much greater ultimate side shear values. The difference in the maximum values of the measured and estimated t-z curves is likely due to unreliability of estimating the compressive strength values in shale, as previously stated.

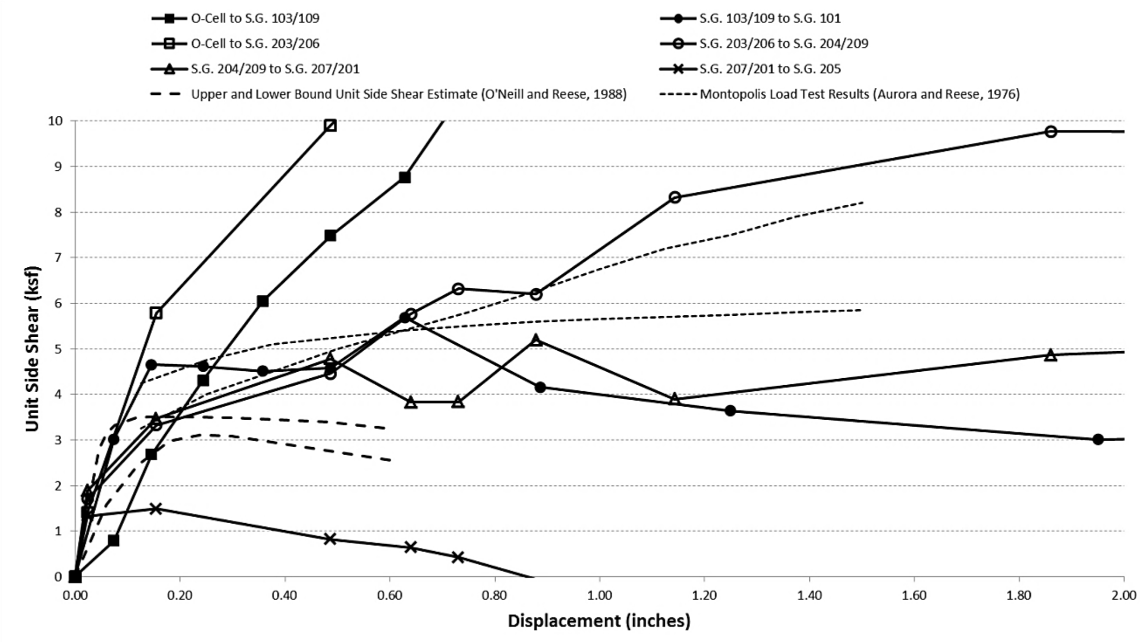


Figure 9.7: T-Z Curves of the Lower Test Shaft Sections, Along with Estimated Unit Side Shear (O'Neill and Reese, 1988) and Measured T-Z Curves from Shaft MT3 (Aurora and Reese, 1976)

The O'Neill and Reese t-z relationships were also plotted with the unit side shear curves of the upper portions of the test shafts (Figure 9.8). The measured t-z curves mimic the shape of the predicted t-z curve. It should also be noted that the t-z curves shown in Figure 9.8 are still increasing, due to the inability to mobilize the upper portions of the test shafts. One key note in the figure is the difference in magnitude of the t-z curve measured for Test Shaft #1 (O-Cell™ to S.G. 105) compared to the other t-z curves (all obtained from Test Shaft #2). The cause of this is uncertain, although the effect could be caused by site variability (even with the close proximity of the two tests) or the lack of comparable strain gauges; preventing a measurement consistency check in the upper portion of Test Shaft #1.

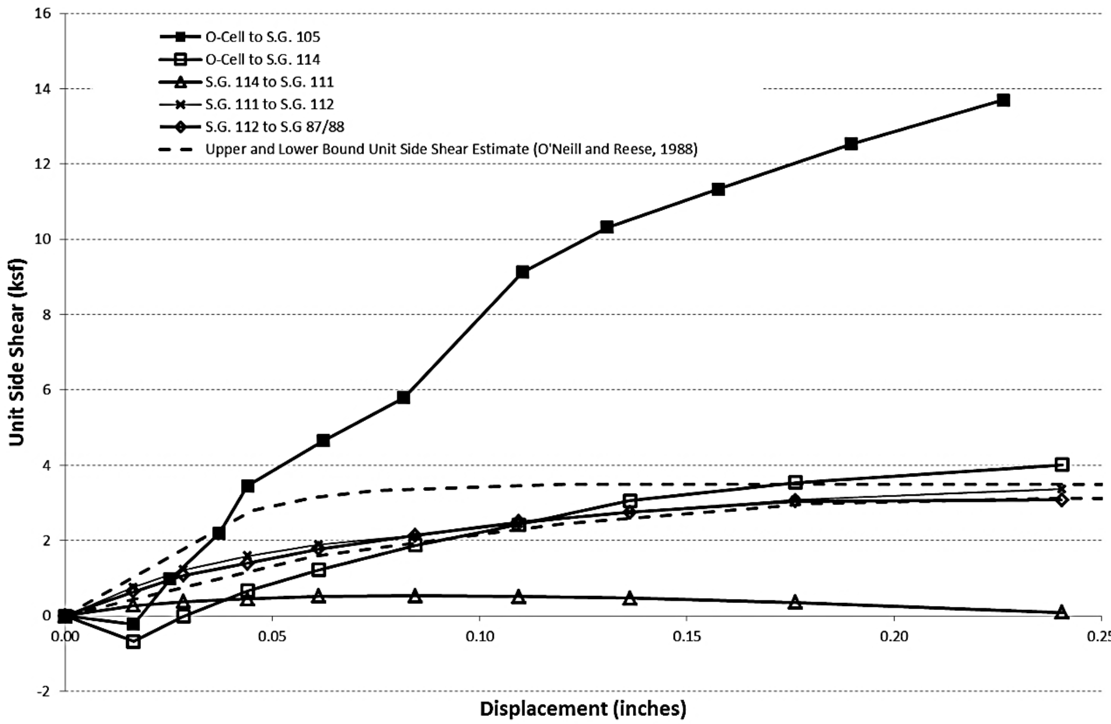


Figure 9.8: Upper Shaft T-Z Curves in Relation to Estimate of Unit Side Shear from O'Neill and Reese (1988)

To further analyze the ultimate unit side shear, the measured values from Test Shafts #1 and #2 are plotted alongside the current TxDOT design curve in Figure 9.9. Also shown, in Figure 9.9, are values from the three O-Cell™ load tests performed in Dallas, TX (Nam and Vipulanandan, 2010), as well as values taken from load tests on similar shales in Missouri (Pierce et al., 2012). The dashed line in the figure corresponds to the empirical relationship created by Nam and Vipulanandan using the values measured from the Dallas O-Cell™ tests, whereas the dash-dotted line is from the Pierce at al. (2012) correlation. Once again, the measured skin friction value from the Dallas O-Cell™ tests with has a TCP value harder than 1-in per 100 blows was performed in limestone. The figure demonstrates that the ultimate skin friction values measured close to the O-Cell™ were close to that predicted from the Nam and Vipulanandan and TxDOT design correlations.

As the measurements approach distances close to the tip of each shaft (primarily within one to two diameters of the tip), the unit side shear decreases significantly. These zones of side resistance were concluded to not be fully mobilized, thus not ultimate values, and are excluded from the plot. Earlier versions of the FHWA drilled shaft manual (O'Neill, 1999) recommended neglecting the side resistance over an area of one diameter above the base of drilled shafts founded in cohesive materials. While this rule was not applied to cohesive IGMs, it seems as though there are zones where very little side resistance mobilizes near the tip of the test shafts. This was disregarded in the latest version of the manual (Brown et al., 2010), allowing the full length of the shaft to contribute to the side resistance (aside from the top 5-ft) in cohesive soils.

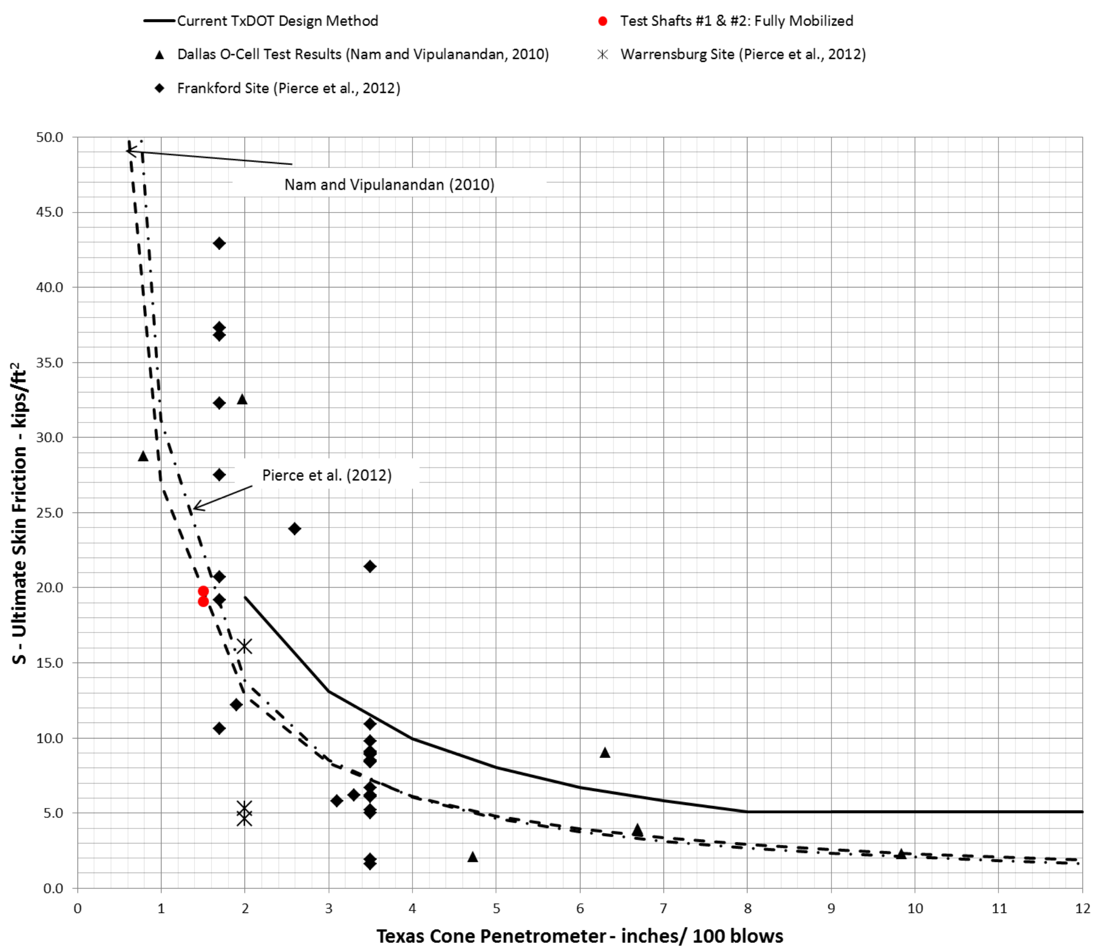


Figure 9.9: Ultimate Skin Friction (ksf) Measured in the Lower Shafts of Test Shaft #1 & #2, in relation to the TxDOT Design Method (TxDOT, 2006), Dallas O-Cell Research Test Results (Nam and Vipulanandan, 2010), and Missouri O-Cell Research Test Results (Pierce et al., 2012)

9.3 MEASURED AXIAL DISPLACEMENTS FOR PREDICTED DESIGN CAPACITIES

A further look into shale-shaft interaction involves examining the axial displacement occurring once the predicted allowable capacity has been reached. Using values from Table 5.1, the allowable capacities for the TxDOT design can be found be applying factors of safety (Side Resistance: 3 and End Bearing: 2) to the ultimate values. The nominal values for the FHWA method were used as the allowable values. Table 9.4

presents the predicted allowable capacities for the rock sockets of each test shaft, using the current TxDOT and FHWA design methods:

Table 9.4: Predicted Allowable Capacities for the Rock Sockets of Test Shaft #1 & #2 (units: kips)

		TxDOT	FHWA
Test Shaft #1	Side Resistance	357	187
	End Bearing	305	245
	$Q_{allowable}$	**662**	**432**
Test Shaft #2	Side Resistance	510	267
	End Bearing	305	245
	$Q_{allowable}$	**815**	**512**

The values of $Q_{allowable}$ are displayed on the load-displacement plot for the rock socket of Test Shaft #1, shown in Figure 9.10. The allowable capacities, in relation to the load-displacement curve measured from the load test, lead to an estimate of the amount of tip movement expected using the corresponding design method for this shaft. The same method is used for the load-displacement curve of Test Shaft #2, presented in Figure 9.11. The estimated settlements of the two design methods are summarized in Table 9.5, under the assumption that the elastic compression of the 7- and 10-ft concrete rock sockets is negligible.

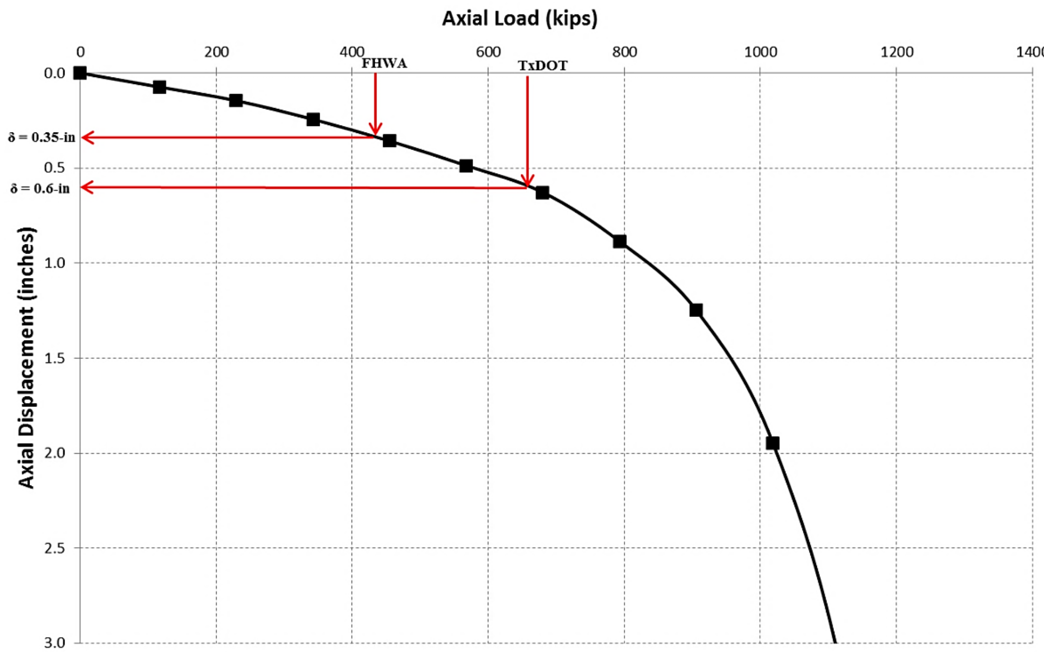


Figure 9.10: Axial Load Corresponding to Predicted TxDOT Design Load for Test Shaft #1

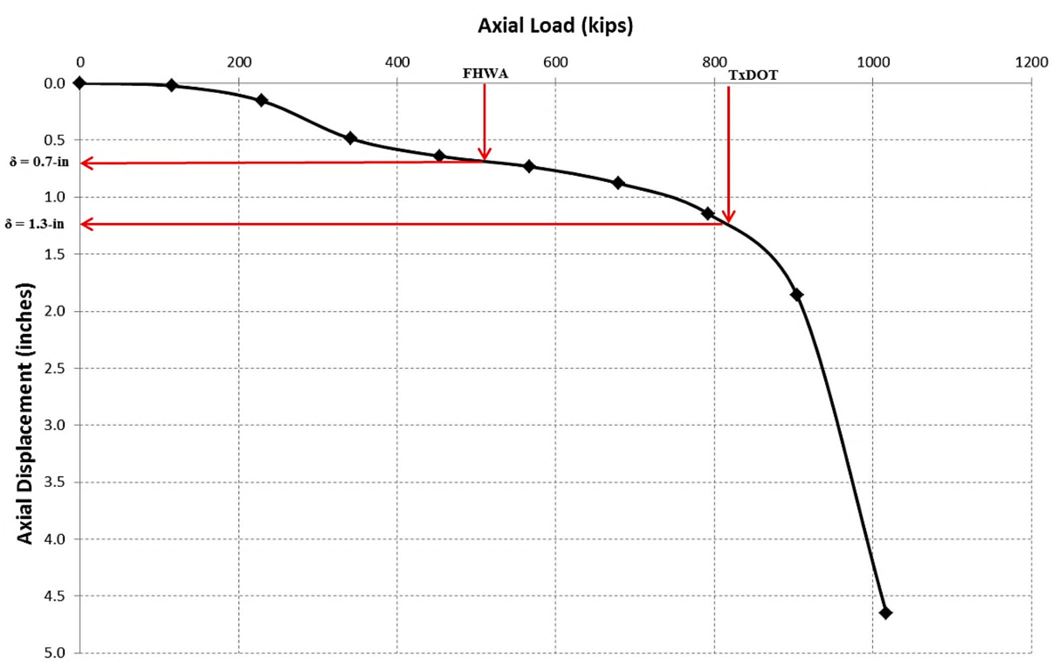


Figure 9.11: Axial Load Corresponding to Predicted TxDOT Design Load for Test Shaft #2

Table 9.5: Estimate Displacements Corresponding to the Predicted Allowable Capacities of the Rock Sockets of Test Shaft #1 & #2 (units: inches)

	TxDOT	**FHWA**
Test Shaft #1	0.6	0.35
Test Shaft #2	1.3	0.7

Chen and Kulhawy (2002) developed curves for a simpler interpretation of load test results by combining the side and base resistances into a single component, presented in Figure 9.12 (also found in the current FHWA drilled shaft manual (Brown et al., 2010)). It should be noted that the curves in Figure 9.12 represent the normalized load-displacement for cohesive and cohesionless soils; however, the cohesive relationship will be applied to the cohesive IGM material in this study for comparison purposes. The load-displacement relationship was converted to "axial compressive force" by applying a "failure threshold" value equal to the ultimate capacity of each test shaft, determined by the FHWA design method. The relationship assumes that failure is reached when the displacement exceeds about 4% of the shaft diameter. Figure 9.13 presents the curves, converted to load-displacement, superimposed on a plot of the measured load-displacement curves for Test Shafts #1 and #2. Comparatively, the shafts in this study displayed a softer response than predicted by Chen and Kulhawy (2002).

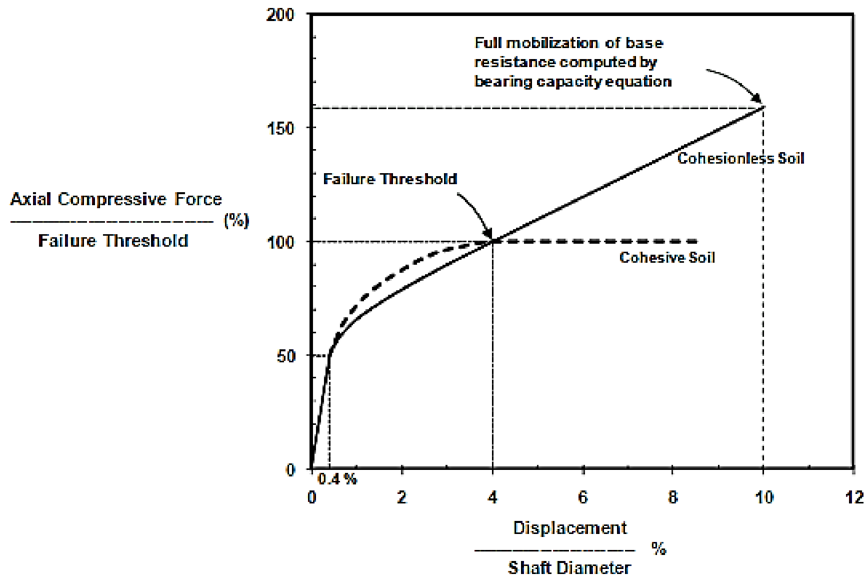


Figure 9.12: Normalized Load-Displacement Curve for Cohesive and Cohesionless Soils (Chen and Kulhawy, 2002)

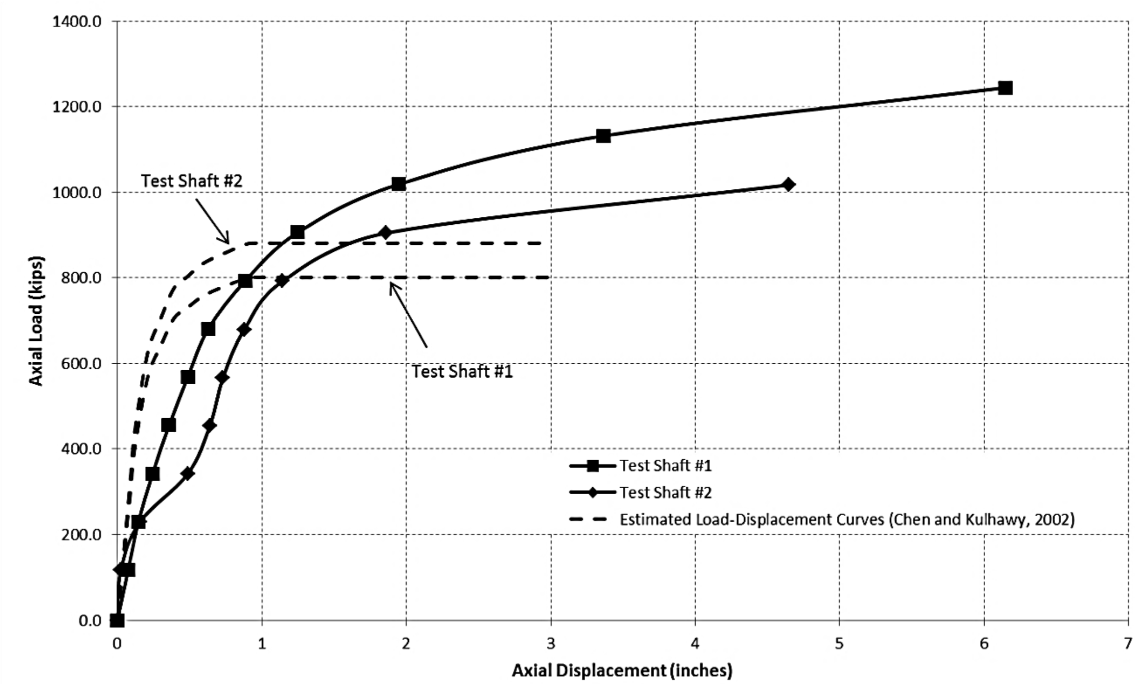


Figure 9.13: Load-Displacement Curves for Test Shaft #1 and #2 in Relation to the Estimated Load-Displacement of Cohesive Soils by Chen and Kulhawy (2002)

Chapter 10: Summary, Conclusions, and Recommendations

10.1 SUMMARY

The focus of this study is to compare the current designs of predicting side resistance and end bearing of drilled shafts socketed in shale. The ability to accurately predict the end bearing and side resistance in shale has been a troublesome task to geotechnical engineers. The inaccuracy of compressive strength testing, due to fissures and cracks in the shale, has led to the development of in-situ strength testing relationships in an attempt to accurately estimate the skin friction and end bearing of shale-shaft interactions.

A well-defined subsurface profile of the soils at the site was developed, along with in-situ and laboratory strength tests. An 80-ft, 30-in diameter, drilled shaft (Test Shaft #1) was installed, equipped with strain gauges and an O-Cell™ placed 7-ft above the tip of the shaft. After the load test of Test Shaft #1, the design of the second drilled shaft occurred (Test Shaft #2) and subsequently installed. Test Shaft #2 was also 80-ft in length and 30-in in diameter, equipped with strain gauges and an O-Cell™ placed at 10-ft above the tip. The placement of the second test was changed with the hope of further mobilizing the upper portion of the test shaft. A careful analysis of the load test results was completed and compared to current design methods and previous research information. End bearing and side resistances measured from the load tests give insight to how the drilled shafts interact with the Taylor Shale that support many highway structures throughout the state.

10.2 CONCLUSIONS

Several conclusions can be made on the information gained from the two load tests performed in this study. The advancement of O-Cell™ technology allowed for the quick testing of an 80-ft drilled shaft, founded in a hard material. Using conventional, top-down, loading, an extensive reaction frame and very large load cell would have been required. The use of O-Cell™ equipment, along with future advancements in the technology, will lead to even better cost-efficient load tests.

The unconfined compressive tests performed on the Taylor Shale showed erratic results throughout the 40-ft of shale strata tested at the site. The varying strengths measured from the laboratory tests caused the FHWA design method to estimate large ranges of side resistance and end bearing. This was anticipated and the results taken from the compressive strength tests on this material should be used with caution.

The failure of some strain gauges caused the stages of the analysis to be questioned, considering that there was no comparison for the loading distributions at some levels within the test shafts. The protection of the strain gauges, especially when concrete is being poured (free-fall) from the ground surface, should be a major concern during the construction of the test shafts. The absence of any strain gauge can cause the measured results to be questioned.

The SoniCaliper lowered before the pouring of concrete indicated that the bottom of each shaft was offset from the true center; 6-in for Test Shaft #1 and 8-in for Test Shaft #2. While this is likely to occur in general production shafts, it could provide insight to the unexpected results measured from the load tests.

Ultimate end bearing values of about 100- and 120-ksf were measured for Test Shafts #1 and #2, respectively. These values are close to the current TxDOT method estimate (125-ksf) for a shaft founded in a soil with a TCP value of 1.5-in per 100 blows, as well as, the nominal FHWA method estimate (100-ksf) for soils with a compressive strength of q_u=20-tsf. The end bearing values measured in this study were similar to those measured in the same material by Aurora and Reese (1976): $q_{p,ult}$=124- to 132-ksf. The ultimate capacity of the rock socket of Test Shaft #1 was about 230-kips greater than that of Test Shaft #2, although Test Shaft #2 contained an extra 3-ft in length available for skin friction.

The ultimate skin friction (for both shafts) was measured at about 20-ksf; in the area closest to the O-Cell™. This value very close to that predicted (19.5-ksf) using the current TxDOT design chart for a soil with a TCP value of 1.5-in per 100 blows. Also, reduction of side shear was observed nearing the tip of the shafts. The side resistance steadily decreased as the zone of measurement moved towards the tip of each shaft, especially within one- to two-diameters of the shaft tip. The side resistances measured in each shaft showed a similar response, therefore, instilling trust in the data provided by the strain gauges.

10.3 RECOMMENDATIONS FOR FUTURE STUDIES

With the completion of this study, several recommendations can be made on future work relating to drilled shaft foundation design. There currently exists a limited amount of information regarding load testing in material with TCP values harder than 2-in per 100 blows, such as encountered in this study. Additional load testing data could allow for a stronger correlation between TCP tests to unit resistances for clay-shales. With the availability of new information on load tests in shales, the current design methods used for drilled shafts should be re-evaluated occasionally to improve the prediction of side shear and end bearing.

The shale-shaft interaction near the tip of drilled shafts should be further evaluated. This study presents results that demonstrate the non-uniformity of side shear within one- to two-diameters of the tip. Methods of designing drilled shafts have disagreed on whether to include the side surface area around the tip in capacity calculations.

Appendix A: Boring Logs

LOG OF BORING NO. B-1

UT Test Drilled Shaft
Austin, Texas
PROJECT NO. 04.30121045

Fugro Consultants, Inc.

SURF. ELEVATION: Unknown

DEPTH, FT	POCKET PEN, tsf / Blows/ft. / REC./RQD, %	STRATUM DESCRIPTION	LAYER ELEV./ DEPTH	WATER CONTENT, %	LIQUID LIMIT, %	PLASTICITY INDEX (PI), %	PASSING NO. 4 SIEVE, %	PASSING NO. 200 SIEVE, %	UNIT DRY WEIGHT, PCF	COMPRESSIVE STRENGTH TSF
		Tan sandy lean CLAY with gravel. (Fill)								
		Tan and light gray fat CLAY, very stiff to hard, blocky, w/sand and ferrous staining. CH (Taylor)	1.0							
		- w/calcareous pockets from 1 to 6 ft								
	N = 20									
5										
	P = 4.5+			20	79	52	98	93		
10										
	P = 4.5+	*- slickensided moderate angle fracture at 14 ft*								
15	15'-20' 100 / 25									
				20	80	53	100	76		
20	20'-25' 89 / 25									
				23					104	1.5(U)
25	25'-30' 83 / 20	[75% water loss at 26.5 ft]								
		- slickensided moderate angle fracture at 26.5 ft								
30	30'-35' 95 / 48									
				25					100	7.7(U)
35	35'-40' 88 / 43	[90% water loss at 35 ft]								
		[100% water return at 37 ft]								

COMPLETION DEPTH: 90.0
DATE DRILLED: 9-4-12
WATER LEVEL / SEEPAGE: See Notes
UPON COMPLETION:

KEY:
N = Standard Penetration Test, bpf
P = Pocket Penetrometer, tsf
U = Unconfined
Q = Unconsolidated Undrained Triaxial

PLATE 3a

FUGRO STD PLATE (AUSTIN) 04.30121045.GPJ FUGRO AUSTIN DATA TEMPLATE.GDT 9/17/12

LOG OF BORING NO. B-1

UT Test Drilled Shaft
Austin, Texas
PROJECT NO. 04.30121045

Fugro Consultants, Inc.

SURF. ELEVATION: Unknown

DEPTH, FT	POCKET PEN, tsf / Blows/ft. / REC./RQD, %	STRATUM DESCRIPTION	LAYER ELEV./ DEPTH	WATER CONTENT, %	LIQUID LIMIT, %	PLASTICITY INDEX (PI), %	PASSING NO. 4 SIEVE, %	PASSING NO. 200 SIEVE, %	UNIT DRY WEIGHT, PCF	COMPRESSIVE STRENGTH TSF
	40'-45' 93 / 76	Tan and light gray fat CLAY, very stiff to hard, blocky, w/sand and ferrous staining. CH (Taylor) *(continued)*								
				28					97	5.1(U)
		- w/dark gray SHALE seams below 43.5 ft (Transition Zone)								
45	45'-50' 98 / 65									
50	50'-55' 100 / 100	Dark gray SHALE, low to moderate hardness, slightly fissile. (Taylor)	50.0							
		- w/occasional tan ferrous-stained moderate angle fractures from 50 to 62 ft								
		- selenite-coated horizontal fracture at 51.2 ft								
55	55'-60' 93 / 89			16					117	20(U)
		- slickensided moderate angle fracture at 56.5 ft								
60	60'-65' 100 / 60									
65	65'-70' 100 / 90									
				20					106	6.9(U)
70	70'-75' 100 / 88									
				18					116	18(U)
75	75'-80' 100 / 67									
		- slickensided moderate angle fracture at 78 ft								

COMPLETION DEPTH: 90.0
DATE DRILLED: 9-4-12
WATER LEVEL / SEEPAGE: See Notes
UPON COMPLETION:

KEY:
N = Standard Penetration Test, bpf
P = Pocket Penetrometer, tsf
U = Unconfined
Q = Unconsolidated Undrained Triaxial

PLATE 3b

FUGRO STD PLATE (AUSTIN) 04.30121045.GPJ FUGRO AUSTIN DATA TEMPLATE.GDT 9/17/12

LOG OF BORING NO. B-1

UT Test Drilled Shaft
Austin, Texas
PROJECT NO. 04.30121045

Fugro Consultants, Inc.

DEPTH, FT	SYMBOL	SAMPLES	POCKET PEN, tsf Blows/ft. REC./RQD, %	STRATUM DESCRIPTION SURF. ELEVATION: Unknown	LAYER ELEV./ DEPTH	WATER CONTENT, %	LIQUID LIMIT, %	PLASTICITY INDEX (PI), %	PASSING NO. 4 SIEVE, %	PASSING NO. 200 SIEVE, %	UNIT DRY WEIGHT, PCF	COMPRESSIVE STRENGTH TSF
			80'-85' 100 / 90	Dark gray SHALE, low to moderate hardness, slightly fissile. (Taylor) *(continued)*								
85			85'-90' 100 / 25			19					111	9.1(U)
90					90.0							
95												
100												
105												
110												
115												

NOTES:
1) Boring was advanced to the 15.0-ft depth using dry drilling technology and groundwater was not encountered above that depth at the time of drilling. Below 15 feet, the boring was advanced to the 90-ft depth using wet drilling technology.
2) As-drilled GPS coordinates - N: 30°13'3.0", W: 97°41'39.0"

COMPLETION DEPTH: 90.0
DATE DRILLED: 9-4-12
WATER LEVEL / SEEPAGE: See Notes
UPON COMPLETION:

KEY:
N = Standard Penetration Test, bpf
P = Pocket Penetrometer, tsf
U = Unconfined
Q = Unconsolidated Undrained Triaxial

PLATE 3c

FUGRO STD PLATE (AUSTIN) 04.30121045.GPJ FUGRO AUSTIN DATA TEMPLATE.GDT 9/17/12

LOG OF BORING NO. B-1A

NORTHING: Unknown
EASTING: Unknown

UT Test Drilled Shaft
Austin, Texas
PROJECT NO. 04.30121045

DEPTH, FT	SYMBOL	SAMPLES	POCKET PEN, tsf Blows/ft. REC./RQD, %	STRATUM DESCRIPTION SURF. ELEVATION: Unknown	LAYER ELEV./ DEPTH	WATER CONTENT, %	LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX (PI), %	PASSING NO. 200 SIEVE, %	UNIT DRY WEIGHT, PCF	UNCONFINED STRENGTH TSF
				Tan sandy lean CLAY with gravel. (Fill)								
				Tan and light gray fat CLAY, very stiff to hard, blocky, w/sand and ferrous staining. CH (Taylor)	1.3							
5			24/12"									
10			44/12"									
15			56/12"									
20			79/12"									
25			69/12"									
30			41/12"									
35			47/12"									

Fugro Consultants, Inc.

COMPLETION DEPTH: 90.5
DATE DRILLED: 10-4-12 to 10-5-12
WATER LEVEL / SEEPAGE: See Notes
WATER LEVEL (): See Notes

KEY:
Note: All depths are measured in feet.
P = Pocket Penetrometer Value, (tsf)
N = Standard Penetration Number

FUGRO STD - W/O PLATE NO. 04.30121045.GPJ FUGRO DATA TEMPLATE 100610.GDT 10/9/12

LOG OF BORING NO. B-1A

NORTHING: Unknown
EASTING: Unknown

UT Test Drilled Shaft
Austin, Texas
PROJECT NO. 04.30121045

SURF. ELEVATION: Unknown

DEPTH, FT	SYMBOL	SAMPLES	POCKET PEN, tsf Blows/ft. REC./RQD, %	STRATUM DESCRIPTION	LAYER ELEV./ DEPTH	WATER CONTENT, %	LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX (PI), %	PASSING NO. 200 SIEVE, %	UNIT DRY WEIGHT, PCF	UNCONFINED STRENGTH TSF
			69/12"	Tan and light gray fat CLAY, very stiff to hard, blocky, w/sand and ferrous staining. CH (Taylor) *(continued)*								
45			100/10.25"									
50			100/5"	Dark gray SHALE, low to moderate hardness, slightly fissile. (Taylor)	49.7							
55			100/2.75"									
60			100/0.75"									
65			100/2"									
70			100/1.75"									
75			100/1.25"									

Fugro Consultants, Inc.

COMPLETION DEPTH: 90.5
DATE DRILLED: 10-4-12 to 10-5-12
WATER LEVEL / SEEPAGE: See Notes
WATER LEVEL (): See Notes

KEY:
Note: All depths are measured in feet.
P = Pocket Penetrometer Value, (tsf)
N = Standard Penetration Number

FUGRO STD - W/O PLATE NO. 04.30121045.GPJ FUGRO DATA TEMPLATE 100610.GDT 10/9/12

LOG OF BORING NO. B-1A

NORTHING: Unknown
EASTING: Unknown

UT Test Drilled Shaft
Austin, Texas
PROJECT NO. 04.30121045

DEPTH, FT	SYMBOL	SAMPLES	POCKET PEN, tsf Blows/ft. REC./RQD, %	STRATUM DESCRIPTION SURF. ELEVATION: Unknown	LAYER ELEV./ DEPTH	WATER CONTENT, %	LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX (PI), %	PASSING NO. 200 SIEVE, %	UNIT DRY WEIGHT, PCF	UNCONFINED STRENGTH TSF
			100/1.5"	Dark gray SHALE, low to moderate hardness, slightly fissile. (Taylor) *(continued)*								
85			100/1.25"									
90			100/0.75"		90.5							
				NOTES: 1) Boring was advanced to the 15-ft depth using dry drilling technology and groundwater was not encountered above that depth at the time of drilling. Below 15 feet, the boring was advanced to the 90.5-ft depth using wet drilling technology.								
95												
100												
105												
110												
115												

Fugro Consultants, Inc.

COMPLETION DEPTH: 90.5
DATE DRILLED: 10-4-12 to 10-5-12
WATER LEVEL / SEEPAGE: See Notes
WATER LEVEL (): See Notes

KEY:
Note: All depths are measured in feet.
P = Pocket Penetrometer Value, (tsf)
N = Standard Penetration Number

FUGRO STD - W/O PLATE NO. 04.30121045.GPJ FUGRO DATA TEMPLATE 100610.GDT 10/9/12

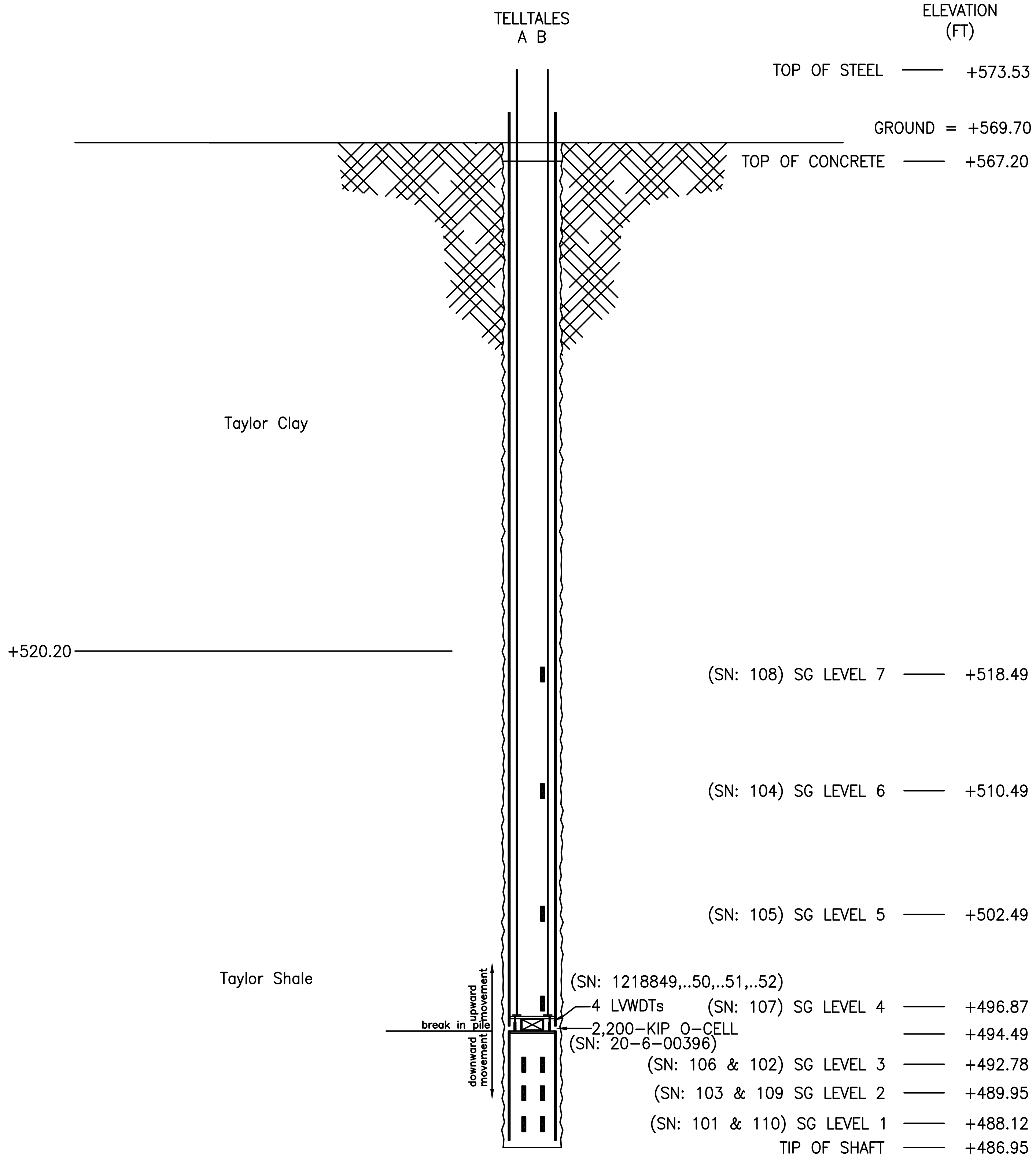
Appendix B: Test Shaft #1

TABLE A: SUMMARY OF DIMENSIONS, ELEVATIONS, AREAS & PROPERTIES FOR ANALYSIS PURPOSES

Shaft: (TS 1, TexDOT - UT - ADSC Research, Austin, TX, LT-9981-1)		
Nominal shaft diameter: EL +567.2 ft to +486.95 ft	=	30 inches
O-cell size: (Serial no.: 20-6-00396)	=	20 inches
Length of concrete from break at base of cell to tip	=	7.5 feet
Shaft shear area from break at base of cell to tip	=	59.2 $feet^2$
Shaft end area	=	4.9 $feet^2$
Weight of shaft from break at base of cell to top of shaft	=	54.7 kips
Estimated shaft unit stiffness: EL +567.2 ft to +486.95 ft	=	2,200,000 kips
Elevation of top of shaft concrete	=	+567.20 feet
Elevation of top of ground surface	=	+569.70 feet
Elevation of break at base of O-cell[1]	=	+494.49 feet
Elevation of shaft tip	=	+486.95 feet
Water elevation was below tip		
Casings:		
NA		
Measured Compression Zones:		
Elevation of top of zone	=	+567.20 feet
Elevation of bottom of telltale (bottom of zone)	=	+495.79 feet
Strain Gages:		
Elevation of strain gage Level 7	=	+518.49 feet
Elevation of strain gage Level 6	=	+510.49 feet
Elevation of strain gage Level 5	=	+502.49 feet
Elevation of strain gage Level 4	=	+496.47 feet
Elevation of strain gage Level 3	=	+492.78 feet
Elevation of strain gage Level 2	=	+489.95 feet
Elevation of strain gage Level 1	=	+488.12 feet
Miscellaneous:		
Concrete strength	=	2430 psi
Top plate diameter	=	24.0 inches
Top plate thickness	=	2.0 inches
Bottom plate diameter	=	24.0 inches
Bottom plate thickness	=	2.0 inches
Reinforcement	=	C-4 Channel - 2 vertical pieces
LVWDT radii at 0, 90,180, 270 degrees orientation	=	11.0 inches

[1]The break between upward and downward movement at the O-cell assembly

NOTE: NOMINAL SHAFT DIAMETER 30inø



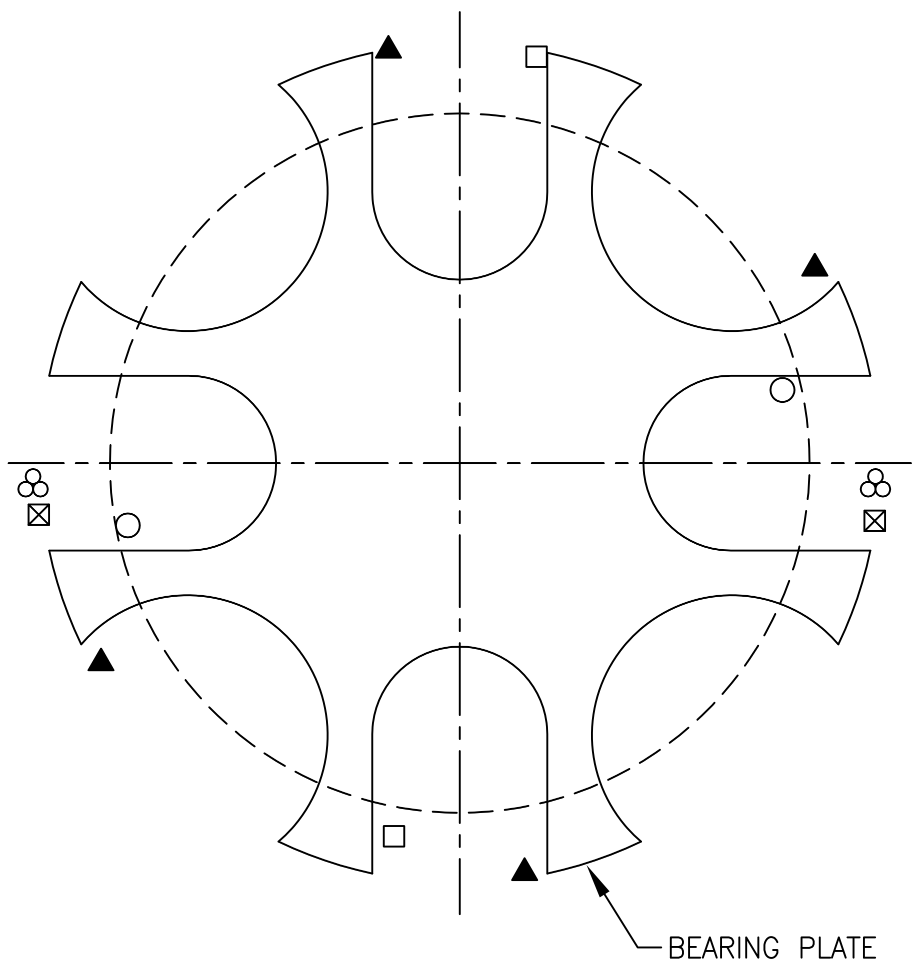
NOTE: SOIL BASED ON BORING DSB #5

LOADTEST
www.LOADTEST.com
2631-D NW 41st St.
Gainesville, FL, 32606
Phone: 800-368-1138
Fax: 352-378-3934

AS BUILT SECTION OF TEST SHAFT

TEXDOT – UT – ADSC RESEARCH – AUSTIN, TX

DWN BY: RCS	DATE: 15 Jun 2012	CHECKED BY:	LT-9981-1
REVISED BY: AJS	DATE: 04 Sep 2012	SCALE: NTS	FIGURE A



LEGEND:

LVWDT	▲
TELLTALE	○
VENT PIPE	□
HYDRAULIC HOSES	⊠
CABLE BUNDLE	ஃ

LOADTEST
www.LOADTEST.com
2631-D NW 41st St.
Gainesville, FL, 32606
Phone: 800-368-1138
Fax: 352-378-3934

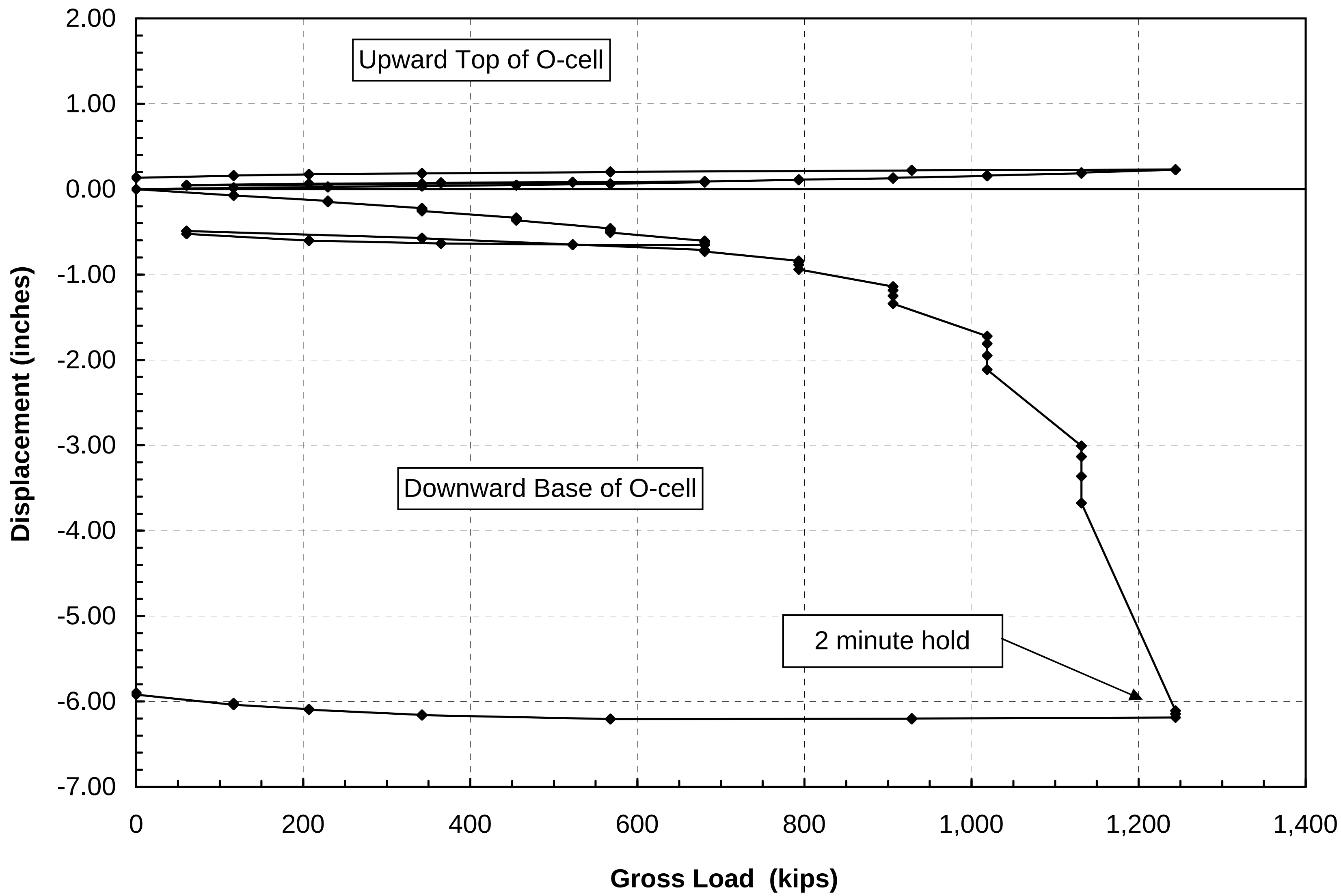
INSTRUMENTATION LAYOUT

TEXDOT – UT – ADSC RESEARCH – AUSTIN, TX

DWN BY: AJS	DATE: 31 Aug 2012	CHECKED BY:	LT-9981
REVISED BY:	DATE:	SCALE: NTS	**FIGURE B**

Osterberg Cell Load vs.Displacement Plots

TexDOT - UT - ADSC Research - Austin, TX - TS 1

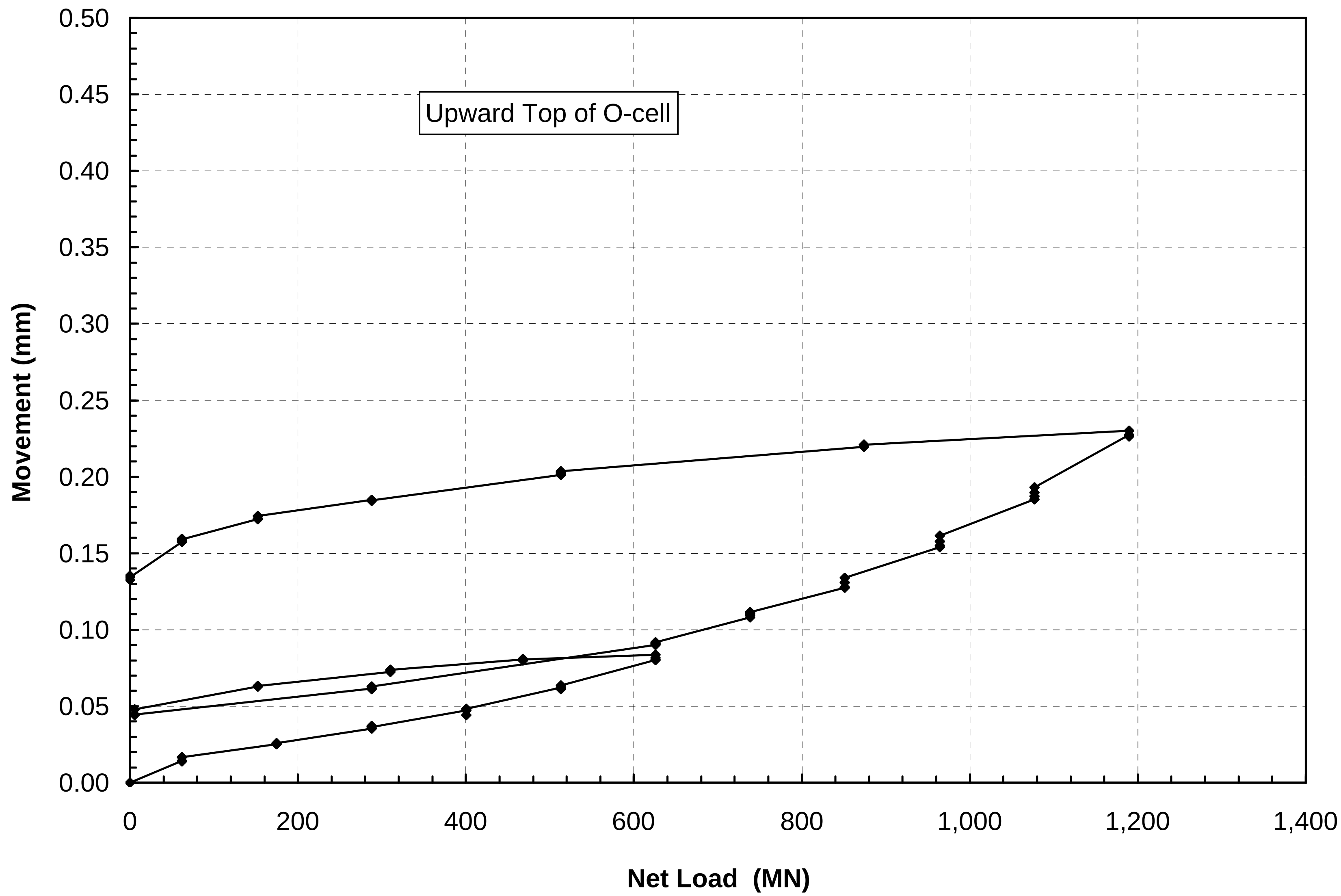


Loadtest Project No. 9981-1

Figure 1A of 6

Osterberg Cell Load vs.Displacement Plots

TexDOT - UT - ADSC Research - Austin, TX - TS 1

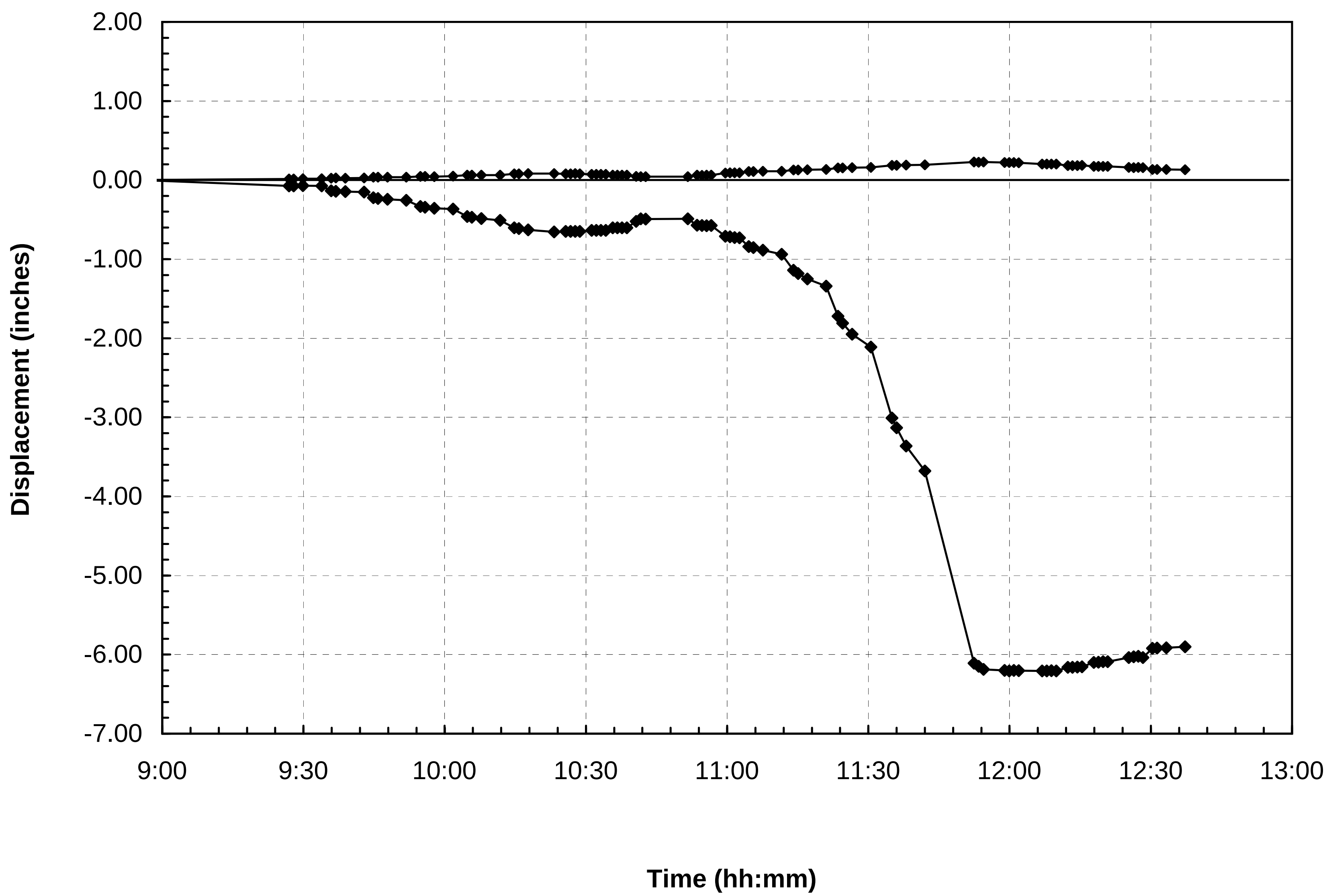


Loadtest Project No. 9981-1

Figure 1B of 6

Osterberg Cell Time vs. Displacement Plots

TexDOT - UT - ADSC Research - Austin, TX - TS 1

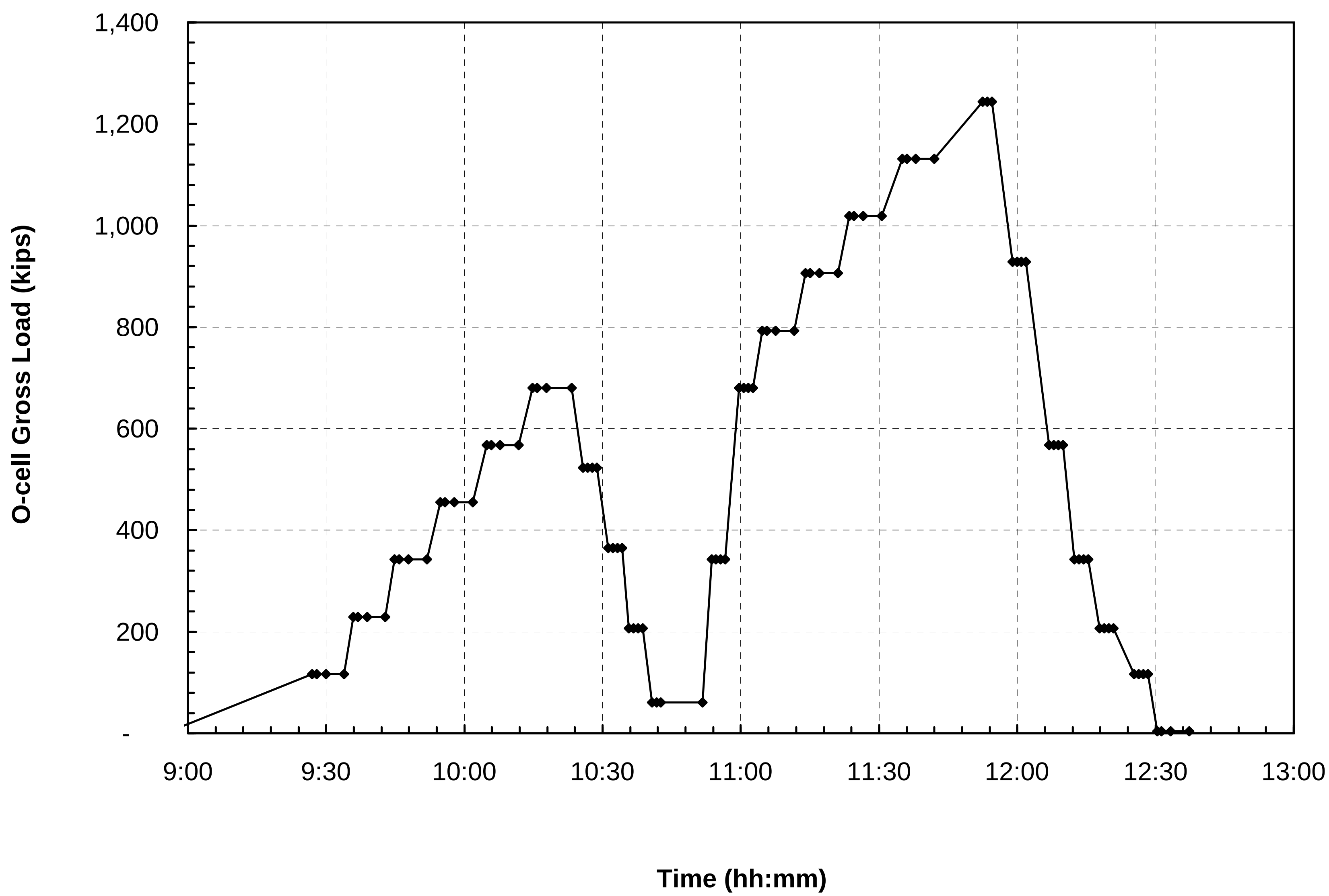


Loadtest Project No. 9981-1

Figure 2 of 6

Osterberg Cell Load vs. Time

TexDOT - UT - ADSC Research - Austin, TX - TS 1

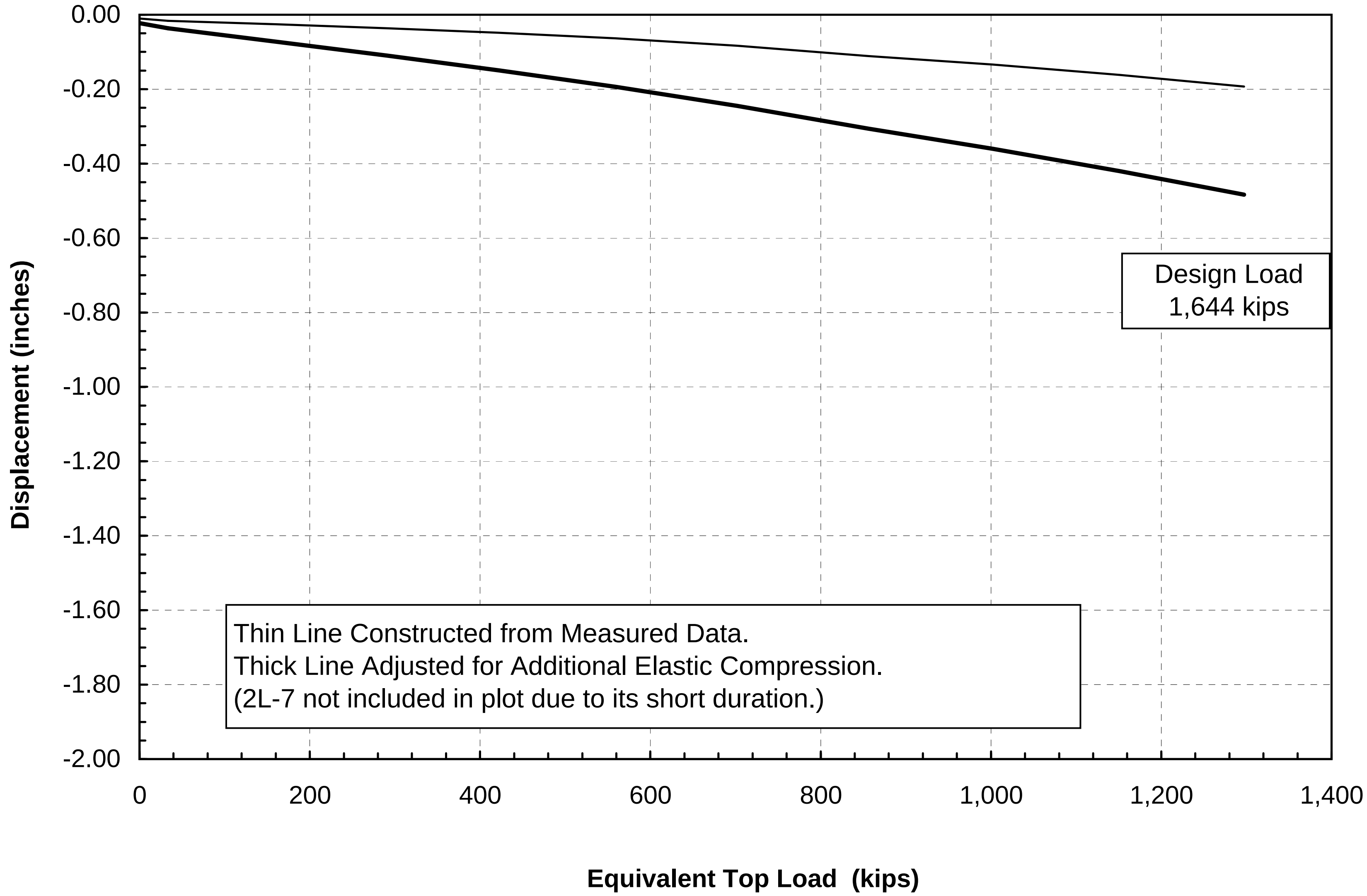


Loadtest Project No. 9981-1

Figure 3 of 6

Equivalent Top Load-Displacement Plots

TexDOT - UT - ADSC Research - Austin, TX - TS 1

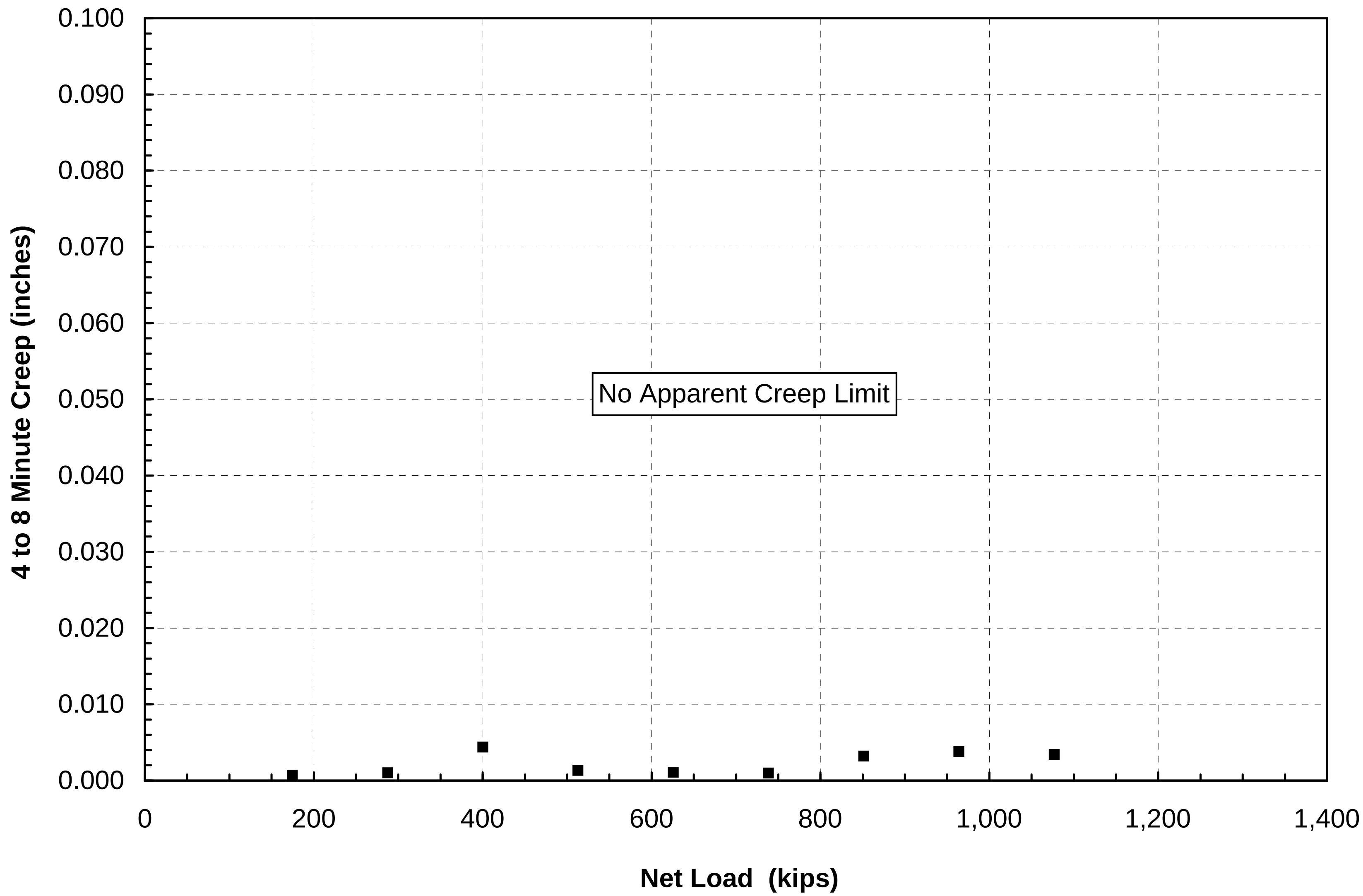


Loadtest Project No. 9981-1

Figure 4 of 6

Side Shear Creep Limit

TexDOT - UT - ADSC Research - Austin, TX - TS 1

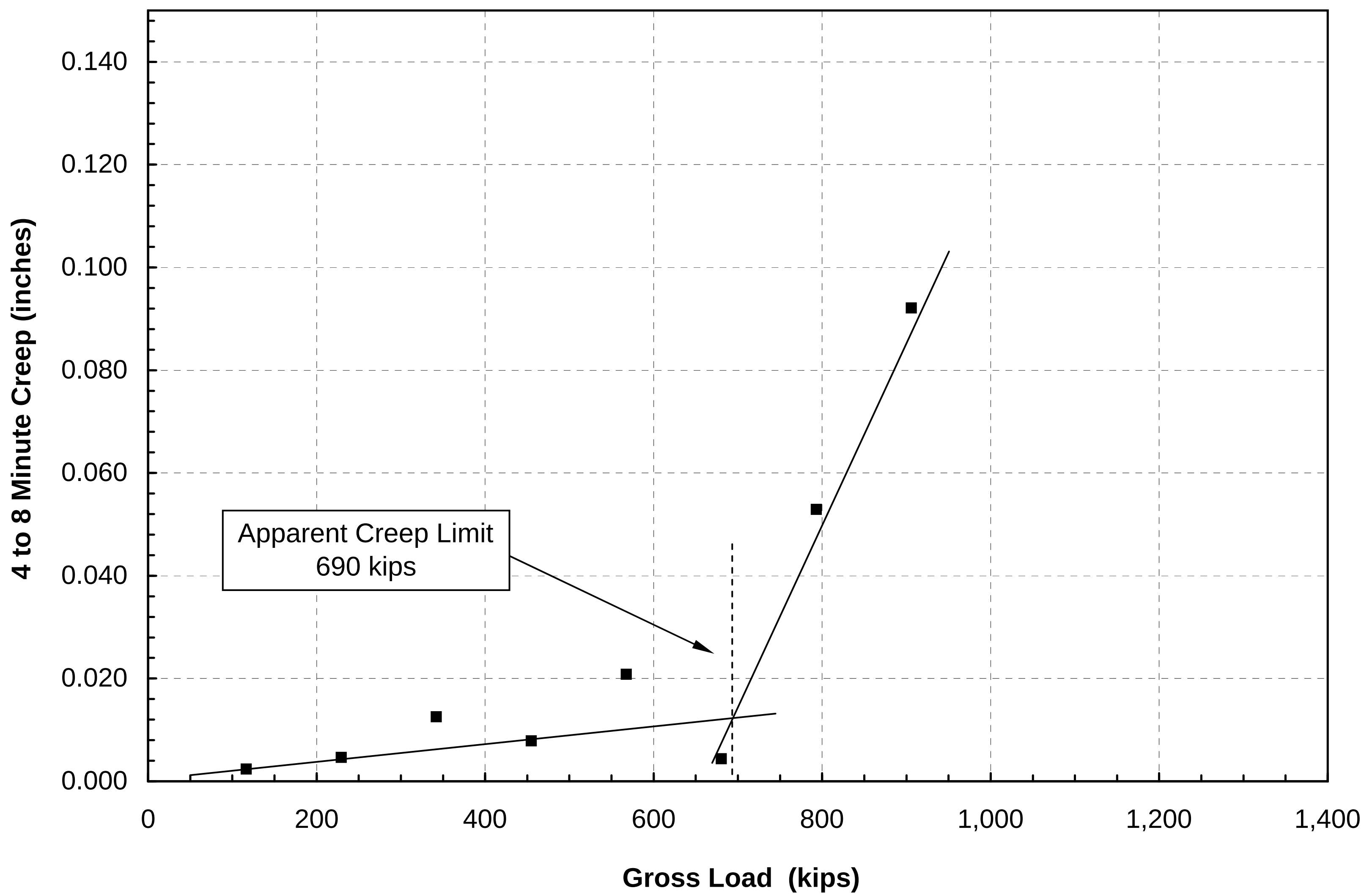


Loadtest Project No. 9981-1

Figure 5 of 6

Base Creep Limit

TexDOT - UT - ADSC Research - Austin, TX - TS 1



Loadtest Project No. 9981-1

Figure 6 of 6

Top of Shaft Movement and Compression

TexDOT - UT - ADSC Research - Austin, TX - TS 1

Load Test Increment	Time (h:m:s)	Time After Start Minutes	O-cell Pressure (psi)	Applied Load (kips)	TOS Indicator Readings Side A (inches)	TOS Indicator Readings Side B (inches)	TOS Indicator Readings Average (inches)	Telltale Compression Side A (inches)	Telltale Compression Side B (inches)	Telltale Compression Average (inches)
1L -0	8:55:00	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000
1L -1	9:27:00	1	500	117	0.005	0.004	0.005	0.009	0.010	0.010
1L -1	9:28:00	2	500	117	0.003	0.005	0.004	0.010	0.010	0.010
1L -1	9:30:00	4	500	117	0.005	0.008	0.007	0.010	0.011	0.010
1L -1	9:34:00	8	500	117	0.002	0.008	0.005	0.012	0.011	0.011
1L -2	9:36:00	1	1,000	230	0.005	0.009	0.007	0.018	0.018	0.018
1L -2	9:37:00	2	1,000	230	0.006	0.008	0.007	0.018	0.018	0.018
1L -2	9:39:00	4	1,000	230	0.004	0.009	0.006	0.019	0.019	0.019
1L -2	9:43:00	8	1,000	230	0.005	0.007	0.006	0.020	0.020	0.020
1L -3	9:45:00	1	1,500	342	0.007	0.008	0.008	0.028	0.028	0.028
1L -3	9:46:00	2	1,500	342	0.007	0.009	0.008	0.028	0.029	0.028
1L -3	9:48:00	4	1,500	342	0.007	0.010	0.008	0.029	0.029	0.029
1L -3	9:52:00	8	1,500	342	0.005	0.010	0.007	0.029	0.029	0.029
1L -4	9:55:00	1	2,000	455	0.008	0.010	0.009	0.038	0.039	0.038
1L -4	9:56:00	2	2,000	455	0.008	0.009	0.009	0.038	0.039	0.038
1L -4	9:58:00	4	2,000	455	0.000	0.011	0.005	0.038	0.039	0.039
1L -4	10:02:00	8	2,000	455	0.010	0.010	0.010	0.038	0.039	0.039
1L -5	10:05:00	1	2,500	568	0.013	0.012	0.012	0.049	0.051	0.050
1L -5	10:06:00	2	2,500	568	0.011	0.012	0.012	0.049	0.051	0.050
1L -5	10:08:00	4	2,500	568	0.012	0.013	0.012	0.049	0.051	0.050
1L -5	10:12:00	8	2,500	568	0.014	0.012	0.013	0.050	0.052	0.051
1L -6	10:15:00	1	3,000	681	0.017	0.017	0.017	0.062	0.065	0.064
1L -6	10:16:00	2	3,000	681	0.016	0.017	0.017	0.062	0.065	0.064
1L -6	10:18:00	4	3,000	681	0.018	0.018	0.018	0.062	0.066	0.064
1L -6	10:23:30	9	3,000	681	0.019	0.020	0.019	0.062	0.066	0.064
1U -1	10:26:00	1	2,300	523	0.019	0.019	0.019	0.060	0.063	0.062
1U -1	10:27:00	2	2,300	523	0.018	0.018	0.018	0.060	0.063	0.062
1U -1	10:28:00	3	2,300	523	0.020	0.019	0.019	0.060	0.063	0.062
1U -1	10:29:00	4	2,300	523	0.020	0.018	0.019	0.060	0.063	0.062
1U -2	10:31:30	1	1,600	365	0.018	0.018	0.018	0.054	0.057	0.056
1U -2	10:32:30	2	1,600	365	0.019	0.018	0.018	0.054	0.056	0.055
1U -2	10:33:30	3	1,600	365	0.019	0.019	0.019	0.054	0.056	0.055
1U -2	10:34:30	4	1,600	365	0.018	0.017	0.018	0.053	0.056	0.055
1U -3	10:36:00	1	900	207	0.017	0.017	0.017	0.045	0.047	0.046
1U -3	10:37:00	2	900	207	0.017	0.017	0.017	0.045	0.046	0.046
1U -3	10:38:00	3	900	207	0.017	0.018	0.018	0.045	0.047	0.046
1U -3	10:39:00	4	900	207	0.017	0.017	0.017	0.045	0.046	0.046
1U -4	10:41:00	1	250	60	0.015	0.014	0.015	0.034	0.033	0.033
1U -4	10:42:00	2	250	60	0.015	0.015	0.015	0.030	0.029	0.029
1U -4	10:43:00	3	250	60	0.015	0.015	0.015	0.030	0.029	0.030
1U -4	10:52:00	12	250	60	0.015	0.014	0.014	0.030	0.030	0.030

Top of Shaft Movement and Compression

TexDOT - UT - ADSC Research - Austin, TX - TS 1

Load Test Increment	Time (h:m:s)	Time After Start Minutes	O-cell Pressure (psi)	Applied Load (kips)	TOS Indicator Readings Side A (inches)	TOS Indicator Readings Side B (inches)	TOS Indicator Readings Average (inches)	Telltale Compression Side A (inches)	Telltale Compression Side B (inches)	Telltale Compression Average (inches)
2L -1	10:54:00	1	1,500	342	0.016	0.016	0.016	0.044	0.046	0.045
2L -1	10:55:00	2	1,500	342	0.014	0.017	0.015	0.045	0.047	0.046
2L -1	10:56:00	3	1,500	342	0.015	0.017	0.016	0.045	0.047	0.046
2L -1	10:57:00	4	1,500	342	0.016	0.017	0.017	0.045	0.047	0.046
2L -2	11:00:00	1	3,000	681	0.022	0.022	0.022	0.066	0.070	0.068
2L -2	11:01:00	2	3,000	681	0.022	0.022	0.022	0.067	0.071	0.069
2L -2	11:02:00	3	3,000	681	0.021	0.022	0.022	0.067	0.071	0.069
2L -2	11:03:00	4	3,000	681	0.023	0.022	0.022	0.067	0.071	0.069
2L -3	11:05:00	1	3,500	793	0.028	0.027	0.028	0.078	0.083	0.081
2L -3	11:06:00	2	3,500	793	0.029	0.029	0.029	0.078	0.083	0.081
2L -3	11:08:00	4	3,500	793	0.028	0.030	0.029	0.079	0.084	0.081
2L -3	11:12:00	8	3,500	793	0.029	0.029	0.029	0.080	0.085	0.082
2L -4	11:14:30	1	4,000	906	0.035	0.035	0.035	0.089	0.095	0.092
2L -4	11:15:30	2	4,000	906	0.035	0.035	0.035	0.090	0.096	0.093
2L -4	11:17:30	4	4,000	906	0.037	0.038	0.037	0.090	0.096	0.093
2L -4	11:21:30	8	4,000	906	0.038	0.041	0.039	0.091	0.098	0.094
2L -5	11:24:00	1	4,500	1,019	0.046	0.049	0.048	0.103	0.110	0.106
2L -5	11:25:00	2	4,500	1,019	0.046	0.049	0.047	0.104	0.111	0.107
2L -5	11:27:00	4	4,500	1,019	0.048	0.050	0.049	0.105	0.112	0.109
2L -5	11:31:00	8	4,500	1,019	0.050	0.054	0.052	0.105	0.113	0.109
2L -6	11:35:30	1	5,000	1,132	0.061	0.065	0.063	0.118	0.127	0.122
2L -6	11:36:30	2	5,000	1,132	0.062	0.067	0.065	0.118	0.127	0.122
2L -6	11:38:30	4	5,000	1,132	0.064	0.068	0.066	0.119	0.128	0.124
2L -6	11:42:30	8	5,000	1,132	0.066	0.071	0.069	0.120	0.129	0.125
2L -7	11:53:00	0	5,500	1,244	0.086	0.089	0.088	0.134	0.145	0.140
2L -7	11:54:00	1	5,500	1,244	0.085	0.089	0.087	0.134	0.145	0.139
2L -7	11:55:00	2	5,500	1,244	0.088	0.091	0.089	0.135	0.146	0.141
2U -1	11:59:30	1	4,100	929	0.086	0.090	0.088	0.127	0.138	0.133
2U -1	12:00:30	2	4,100	929	0.088	0.089	0.089	0.127	0.138	0.132
2U -1	12:01:30	3	4,100	929	0.087	0.091	0.089	0.127	0.137	0.132
2U -1	12:02:30	4	4,100	929	0.085	0.091	0.088	0.126	0.137	0.132
2U -2	12:07:30	1	2,500	568	0.087	0.090	0.089	0.110	0.119	0.115
2U -2	12:08:30	2	2,500	568	0.086	0.089	0.088	0.110	0.119	0.115
2U -2	12:09:30	3	2,500	568	0.087	0.090	0.088	0.109	0.119	0.114
2U -2	12:10:30	4	2,500	568	0.086	0.089	0.087	0.109	0.119	0.114
2U -3	12:13:00	1	1,500	342	0.083	0.087	0.085	0.096	0.104	0.100
2U -3	12:14:00	2	1,500	342	0.083	0.087	0.085	0.095	0.104	0.099
2U -3	12:15:00	3	1,500	342	0.083	0.087	0.085	0.095	0.103	0.099
2U -3	12:16:00	4	1,500	342	0.085	0.086	0.085	0.095	0.103	0.099
2U -4	12:18:30	1	900	207	0.083	0.086	0.085	0.086	0.093	0.090
2U -4	12:19:30	2	900	207	0.081	0.085	0.083	0.086	0.093	0.089
2U -4	12:20:30	3	900	207	0.083	0.085	0.084	0.085	0.092	0.089
2U -4	12:21:30	4	900	207	0.082	0.086	0.084	0.085	0.092	0.088
2U -5	12:26:00	1	500	117	0.079	0.082	0.080	0.076	0.082	0.079
2U -5	12:27:00	2	500	117	0.078	0.082	0.080	0.075	0.081	0.078
2U -5	12:28:00	3	500	117	0.080	0.083	0.082	0.075	0.081	0.078
2U -5	12:29:00	4	500	117	0.077	0.082	0.080	0.075	0.081	0.078
2U -6	12:31:00	1	0	0	0.072	0.078	0.075	0.058	0.061	0.059
2U -6	12:32:00	2	0	0	0.074	0.078	0.076	0.057	0.061	0.059
2U -6	12:34:00	4	0	0	0.074	0.079	0.076	0.057	0.061	0.059
2U -6	12:38:00	8	0	0	0.072	0.077	0.075	0.056	0.059	0.058

O-cell Expansion

TexDOT - UT - ADSC Research - Austin, TX - TS 1

Load Test Increment	Time (h:m:s)	Time After Start Minutes	O-cell Pressure (psi)	Applied Load (kips)	LVWDT Readings (Expansion) 12-18849 (inches)	12-18850 (inches)	12-18851 (inches)	12-18852 (inches)	Average[1] (inches)
1L -0	8:55:00	0	0	0	0.000	0.000	0.000	0.000	0.000
1L -1	9:27:00	1	500	117	0.097	0.072	0.076	0.017	0.087
1L -1	9:28:00	2	500	117	0.097	0.072	0.076	0.020	0.087
1L -1	9:30:00	4	500	117	0.099	0.073	0.078	0.017	0.088
1L -1	9:34:00	8	500	117	0.101	0.075	0.079	0.020	0.090
1L -2	9:36:00	1	1,000	230	0.179	0.137	0.144	0.066	0.161
1L -2	9:37:00	2	1,000	230	0.184	0.141	0.149	0.074	0.166
1L -2	9:39:00	4	1,000	230	0.189	0.148	0.153	0.073	0.171
1L -2	9:43:00	8	1,000	230	0.193	0.153	0.159	0.076	0.176
1L -3	9:45:00	1	1,500	342	0.281	0.222	0.237	0.145	0.259
1L -3	9:46:00	2	1,500	342	0.293	0.234	0.249	0.168	0.271
1L -3	9:48:00	4	1,500	342	0.306	0.245	0.256	0.169	0.281
1L -3	9:52:00	8	1,500	342	0.319	0.257	0.266	0.187	0.292
1L -4	9:55:00	1	2,000	455	0.412	0.339	0.350	0.264	0.381
1L -4	9:56:00	2	2,000	455	0.419	0.343	0.359	0.268	0.389
1L -4	9:58:00	4	2,000	455	0.433	0.356	0.371	0.287	0.402
1L -4	10:02:00	8	2,000	455	0.445	0.368	0.382	0.295	0.414
1L -5	10:05:00	1	2,500	568	0.560	0.467	0.483	0.369	0.522
1L -5	10:06:00	2	2,500	568	0.572	0.478	0.494	0.420	0.533
1L -5	10:08:00	4	2,500	568	0.587	0.492	0.511	0.422	0.549
1L -5	10:12:00	8	2,500	568	0.611	0.513	0.532	0.441	0.571
1L -6	10:15:00	1	3,000	681	0.735	0.615	0.634	0.518	0.685
1L -6	10:16:00	2	3,000	681	0.744	0.624	0.643	0.517	0.693
1L -6	10:18:00	4	3,000	681	0.760	0.640	0.660	0.570	0.710
1L -6	10:23:30	9	3,000	681	0.789	0.665	0.686	0.586	0.737
1U -1	10:26:00	1	2,300	523	0.786	0.660	0.676	0.593	0.731
1U -1	10:27:00	2	2,300	523	0.785	0.660	0.676	0.595	0.730
1U -1	10:28:00	3	2,300	523	0.785	0.660	0.677	0.596	0.731
1U -1	10:29:00	4	2,300	523	0.785	0.660	0.676	0.593	0.730
1U -2	10:31:30	1	1,600	365	0.763	0.644	0.657	0.604	0.710
1U -2	10:32:30	2	1,600	365	0.762	0.642	0.655	0.607	0.708
1U -2	10:33:30	3	1,600	365	0.764	0.641	0.654	0.608	0.709
1U -2	10:34:30	4	1,600	365	0.763	0.641	0.655	0.606	0.709
1U -3	10:36:00	1	900	207	0.711	0.603	0.619	0.619	0.665
1U -3	10:37:00	2	900	207	0.712	0.603	0.619	0.616	0.666
1U -3	10:38:00	3	900	207	0.713	0.603	0.618	0.616	0.666
1U -3	10:39:00	4	900	207	0.713	0.602	0.618	0.615	0.665
1U -4	10:41:00	1	250	60	0.603	0.526	0.540	0.599	0.571
1U -4	10:42:00	2	250	60	0.557	0.492	0.513	0.570	0.535
1U -4	10:43:00	3	250	60	0.569	0.495	0.507	0.568	0.538
1U -4	10:52:00	12	250	60	0.564	0.490	0.503	0.568	0.533

O-cell Expansion

TexDOT - UT - ADSC Research - Austin, TX - TS 1

Load Test Increment	Time (h:m:s)	Time After Start Minutes	O-cell Pressure (psi)	Applied Load (kips)	LVWDT Readings (Expansion) 12-18849 (inches)	12-18850 (inches)	12-18851 (inches)	12-18852 (inches)	Average[1] (inches)
2L -1	10:54:00	1	1,500	342	0.680	0.572	0.586	0.552	0.633
2L -1	10:55:00	2	1,500	342	0.682	0.574	0.589	0.554	0.635
2L -1	10:56:00	3	1,500	342	0.685	0.573	0.590	0.553	0.638
2L -1	10:57:00	4	1,500	342	0.683	0.575	0.592	0.552	0.637
2L -2	11:00:00	1	3,000	681	0.858	0.725	0.746	0.627	0.802
2L -2	11:01:00	2	3,000	681	0.865	0.733	0.753	0.641	0.809
2L -2	11:02:00	3	3,000	681	0.872	0.740	0.760	0.640	0.816
2L -2	11:03:00	4	3,000	681	0.879	0.746	0.764	0.652	0.821
2L -3	11:05:00	1	3,500	793	1.011	0.862	0.887	0.773	0.949
2L -3	11:06:00	2	3,500	793	1.027	0.877	0.901	0.787	0.964
2L -3	11:08:00	4	3,500	793	1.059	0.911	0.934	0.805	0.997
2L -3	11:12:00	8	3,500	793	1.114	0.963	0.987	0.860	1.051
2L -4	11:14:30	1	4,000	906	1.333	1.176	1.201	1.081	1.267
2L -4	11:15:30	2	4,000	906	1.378	1.214	1.242	1.129	1.310
2L -4	11:17:30	4	4,000	906	1.448	1.285	1.313	1.175	1.380
2L -4	11:21:30	8	4,000	906	1.542	1.379	1.409	1.278	1.475
2L -5	11:24:00	1	4,500	1,019	1.945	1.770	1.804	1.694	1.875
2L -5	11:25:00	2	4,500	1,019	2.033	1.854	1.895	1.767	1.964
2L -5	11:27:00	4	4,500	1,019	2.176	2.000	2.039	1.933	2.107
2L -5	11:31:00	8	4,500	1,019	2.343	2.162	2.205	2.073	2.274
2L -6	11:35:30	1	5,000	1,132	3.260	3.076	3.129	2.977	3.194
2L -6	11:36:30	2	5,000	1,132	3.384	3.207	3.253	3.119	3.319
2L -6	11:38:30	4	5,000	1,132	3.618	3.434	3.488	3.338	3.553
2L -6	11:42:30	8	5,000	1,132	3.937	3.758	3.805	3.654	3.871
2L -7	11:53:00	0	5,500	1,244	6.246	6.391	6.425	4.574	6.335
2L -7	11:54:00	1	5,500	1,244	6.290	6.561	6.456	6.268	6.373
2L -7	11:55:00	2	5,500	1,244	6.333	6.619	6.505	6.282	6.419
2U -1	11:59:30	1	4,100	929	6.335	6.614	6.509	1.530	6.422
2U -1	12:00:30	2	4,100	929	6.340	6.613	6.514	1.965	6.427
2U -1	12:01:30	3	4,100	929	6.336	6.616	6.504	4.864	6.420
2U -1	12:02:30	4	4,100	929	6.340	6.614	6.509	6.336	6.424
2U -2	12:07:30	1	2,500	568	6.328	6.578	6.492	4.797	6.410
2U -2	12:08:30	2	2,500	568	6.327	6.583	6.489	3.333	6.408
2U -2	12:09:30	3	2,500	568	6.331	6.573	6.484	6.301	6.408
2U -2	12:10:30	4	2,500	568	6.328	6.577	6.488	4.932	6.408
2U -3	12:13:00	1	1,500	342	6.280	6.504	6.410	6.283	6.345
2U -3	12:14:00	2	1,500	342	6.276	6.505	6.414	5.011	6.345
2U -3	12:15:00	3	1,500	342	6.276	6.503	6.407	3.281	6.342
2U -3	12:16:00	4	1,500	342	6.277	6.498	6.406	6.198	6.341
2U -4	12:18:30	1	900	207	6.203	6.443	6.342	6.179	6.273
2U -4	12:19:30	2	900	207	6.197	6.424	6.339	1.929	6.268
2U -4	12:20:30	3	900	207	6.196	6.430	6.331	6.291	6.263
2U -4	12:21:30	4	900	207	6.190	6.432	6.334	4.873	6.262
2U -5	12:26:00	1	500	117	6.118	6.367	6.279	6.317	6.199
2U -5	12:27:00	2	500	117	6.105	6.352	6.266	4.348	6.186
2U -5	12:28:00	3	500	117	6.100	6.367	6.263	6.292	6.181
2U -5	12:29:00	4	500	117	6.117	6.347	6.275	5.077	6.196
2U -6	12:31:00	1	0	0	5.956	6.234	6.155	4.903	6.055
2U -6	12:32:00	2	0	0	5.961	6.226	6.146	3.138	6.054
2U -6	12:34:00	4	0	0	5.954	6.223	6.147	4.848	6.051
2U -6	12:38:00	8	0	0	5.939	6.214	6.126	4.367	6.033

[1]LVWDT 12-18852 did not function properly. LVWDT 12-18849,,51 are used in average.

Upward and Downward Movement and Creep

TexDOT - UT - ADSC Research - Austin, TX - TS 1

Load Test Increment	Time 0 (h:m:s)	Time After Start Minutes	O-cell Pressure (psi)	Applied Load (kips)	Net Load kips (kips)	Top O-cell Movement (inches)	Upward Creep (inches)	Bottom O-cell Movement (inches)	Downward Creep (inches)
1L -0	8:55:00	0	0	0	0	0.000		0.000	
1L -1	9:27:00	1	500	117	62	0.014		-0.072	
1L -1	9:28:00	2	500	117	62	0.014		-0.073	
1L -1	9:30:00	4	500	117	62	0.017		-0.071	
1L -1	9:34:00	8	500	117	62	0.017	0.000	-0.074	0.002
1L -2	9:36:00	1	1,000	230	175	0.025		-0.136	
1L -2	9:37:00	2	1,000	230	175	0.026		-0.141	
1L -2	9:39:00	4	1,000	230	175	0.025		-0.145	
1L -2	9:43:00	8	1,000	230	175	0.026	0.001	-0.150	0.005
1L -3	9:45:00	1	1,500	342	288	0.036		-0.223	
1L -3	9:46:00	2	1,500	342	288	0.037		-0.235	
1L -3	9:48:00	4	1,500	342	288	0.037		-0.244	
1L -3	9:52:00	8	1,500	342	288	0.036	-0.001	-0.256	0.013
1L -4	9:55:00	1	2,000	455	400	0.047		-0.334	
1L -4	9:56:00	2	2,000	455	400	0.047		-0.342	
1L -4	9:58:00	4	2,000	455	400	0.044		-0.358	
1L -4	10:02:00	8	2,000	455	400	0.048	0.004	-0.365	0.008
1L -5	10:05:00	1	2,500	568	513	0.062		-0.460	
1L -5	10:06:00	2	2,500	568	513	0.061		-0.472	
1L -5	10:08:00	4	2,500	568	513	0.062		-0.487	
1L -5	10:12:00	8	2,500	568	513	0.064	0.001	-0.508	0.021
1L -6	10:15:00	1	3,000	681	626	0.080		-0.604	
1L -6	10:16:00	2	3,000	681	626	0.080		-0.613	
1L -6	10:18:00	4	3,000	681	626	0.082		-0.628	
1L -6	10:23:30	9	3,000	681	626	0.083		-0.654	
1U -1	10:26:00	1	2,300	523	468	0.081		-0.650	
1U -1	10:27:00	2	2,300	523	468	0.080		-0.650	
1U -1	10:28:00	3	2,300	523	468	0.081		-0.650	
1U -1	10:29:00	4	2,300	523	468	0.081		-0.650	
1U -2	10:31:30	1	1,600	365	310	0.074		-0.636	
1U -2	10:32:30	2	1,600	365	310	0.073		-0.635	
1U -2	10:33:30	3	1,600	365	310	0.074		-0.635	
1U -2	10:34:30	4	1,600	365	310	0.073		-0.636	
1U -3	10:36:00	1	900	207	152	0.063		-0.602	
1U -3	10:37:00	2	900	207	152	0.063		-0.603	
1U -3	10:38:00	3	900	207	152	0.063		-0.603	
1U -3	10:39:00	4	900	207	152	0.063		-0.603	
1U -4	10:41:00	1	250	60	6	0.048		-0.523	
1U -4	10:42:00	2	250	60	6	0.044		-0.490	
1U -4	10:43:00	3	250	60	6	0.044		-0.494	
1U -4	10:52:00	12	250	60	6	0.044		-0.489	

Upward and Downward Movement and Creep

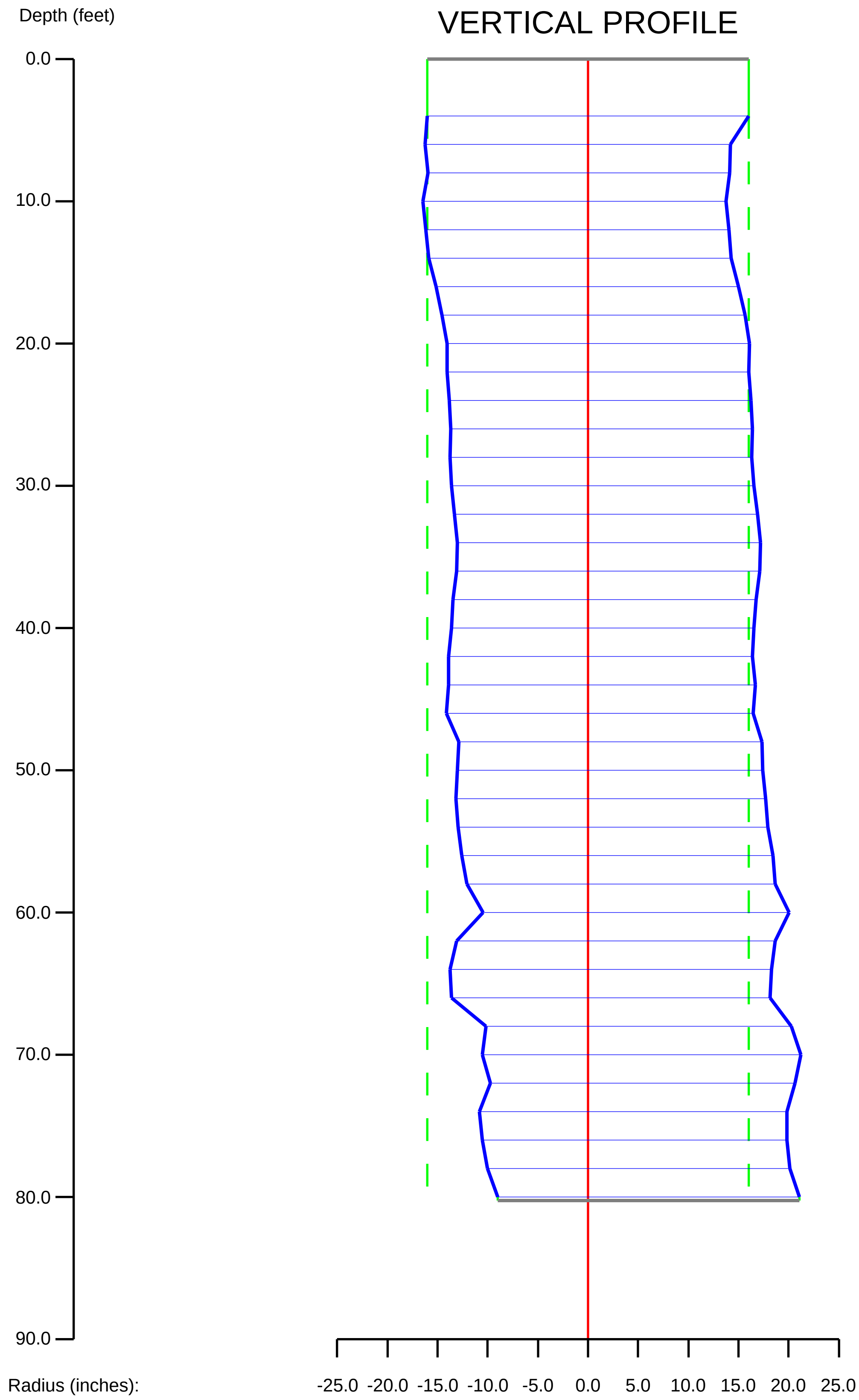
TexDOT - UT - ADSC Research - Austin, TX - TS 1

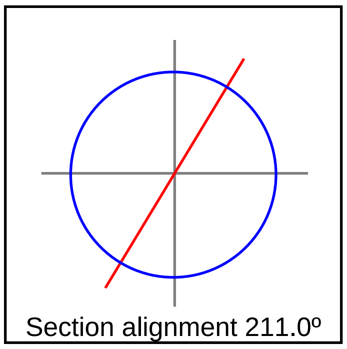
Load Test Increment	Time 0 (h:m:s)	Time After Start Minutes	O-cell Pressure (psi)	Applied Load (kips)	Net Load kips (kips)	Top O-cell Movement (inches)	Upward Creep (inches)	Bottom O-cell Movement (inches)	Downward Creep (inches)
2L -1	10:54:00	1	1,500	342	288	0.062		-0.571	
2L -1	10:55:00	2	1,500	342	288	0.061		-0.574	
2L -1	10:56:00	3	1,500	342	288	0.062		-0.576	
2L -1	10:57:00	4	1,500	342	288	0.063	0.001	-0.574	-0.001
2L -2	11:00:00	1	3,000	681	626	0.090		-0.712	
2L -2	11:01:00	2	3,000	681	626	0.091		-0.718	
2L -2	11:02:00	3	3,000	681	626	0.091		-0.725	
2L -2	11:03:00	4	3,000	681	626	0.092	0.001	-0.730	0.004
2L -3	11:05:00	1	3,500	793	739	0.108		-0.841	
2L -3	11:06:00	2	3,500	793	739	0.109		-0.855	
2L -3	11:08:00	4	3,500	793	739	0.110		-0.886	
2L -3	11:12:00	8	3,500	793	739	0.111	0.001	-0.939	0.053
2L -4	11:14:30	1	4,000	906	851	0.127		-1.140	
2L -4	11:15:30	2	4,000	906	851	0.128		-1.182	
2L -4	11:17:30	4	4,000	906	851	0.131		-1.249	
2L -4	11:21:30	8	4,000	906	851	0.134	0.003	-1.341	0.092
2L -5	11:24:00	1	4,500	1,019	964	0.154		-1.721	
2L -5	11:25:00	2	4,500	1,019	964	0.155		-1.809	
2L -5	11:27:00	4	4,500	1,019	964	0.158		-1.950	
2L -5	11:31:00	8	4,500	1,019	964	0.161	0.004	-2.113	0.163
2L -6	11:35:30	1	5,000	1,132	1,077	0.185		-3.009	
2L -6	11:36:30	2	5,000	1,132	1,077	0.187		-3.131	
2L -6	11:38:30	4	5,000	1,132	1,077	0.190		-3.363	
2L -6	11:42:30	8	5,000	1,132	1,077	0.193	0.003	-3.678	0.315
2L -7	11:53:00	0	5,500	1,244	1,190	0.227		-6.108	
2L -7	11:54:00	1	5,500	1,244	1,190	0.226		-6.147	
2L -7	11:55:00	2	5,500	1,244	1,190	0.230		-6.189	
2U -1	11:59:30	1	4,100	929	874	0.221		-6.201	
2U -1	12:00:30	2	4,100	929	874	0.221		-6.206	
2U -1	12:01:30	3	4,100	929	874	0.221		-6.199	
2U -1	12:02:30	4	4,100	929	874	0.219		-6.205	
2U -2	12:07:30	1	2,500	568	513	0.204		-6.206	
2U -2	12:08:30	2	2,500	568	513	0.202		-6.206	
2U -2	12:09:30	3	2,500	568	513	0.203		-6.205	
2U -2	12:10:30	4	2,500	568	513	0.201		-6.207	
2U -3	12:13:00	1	1,500	342	288	0.185		-6.160	
2U -3	12:14:00	2	1,500	342	288	0.184		-6.161	
2U -3	12:15:00	3	1,500	342	288	0.184		-6.157	
2U -3	12:16:00	4	1,500	342	288	0.185		-6.157	
2U -4	12:18:30	1	900	207	152	0.174		-6.098	
2U -4	12:19:30	2	900	207	152	0.172		-6.096	
2U -4	12:20:30	3	900	207	152	0.173		-6.091	
2U -4	12:21:30	4	900	207	152	0.172		-6.090	
2U -5	12:26:00	1	500	117	62	0.159		-6.040	
2U -5	12:27:00	2	500	117	62	0.158		-6.028	
2U -5	12:28:00	3	500	117	62	0.159		-6.022	
2U -5	12:29:00	4	500	117	62	0.157		-6.039	
2U -6	12:31:00	1	0	0	0	0.134		-5.921	
2U -6	12:32:00	2	0	0	0	0.135		-5.919	
2U -6	12:34:00	4	0	0	0	0.135		-5.915	
2U -6	12:38:00	8	0	0	0	0.132		-5.900	

Load	Time	Time After	O-cell	Applied	Level 1		Level 2		Level 3				Level 4	
Test		Start	Pressure	Load	105	Av. Load	107	Av. Load	103	109	Av. Strain	Av. Load	101	Av. Load
Increment	(h:m:s)	Minutes	(psi)	(kips)	με	(kips)	με	(kips)	με	με	με	(kips)	με	(kips)
1L -0	8:55:00	0	0	0	0	0	0	0	0	0	0	0	0	0
1L -1	9:27:00	1	500	117	-37	73	-74	146	-45	-39	-42	83	-21	42
1L -1	9:28:00	2	500	117	-37	73	-75	149	-45	-39	-42	83	-21	42
1L -1	9:30:00	4	500	117	-37	74	-74	146	-47	-39	-43	84	-21	42
1L -1	9:34:00	8	500	117	-37	74	-81	161	-49	-42	-46	91	-24	47
1L -2	9:36:00	1	1,000	230	-62	123	-130	258	-78	-60	-69	137	-36	72
1L -2	9:37:00	2	1,000	230	-62	123	-131	261	-79	-62	-71	141	-38	75
1L -2	9:39:00	4	1,000	230	-62	123	-132	263	-80	-62	-71	142	-38	75
1L -2	9:43:00	8	1,000	230	-67	133	-151	300	-91	-69	-80	159	-46	92
1L -3	9:45:00	1	1,500	342	-87	172	-190	376	-110	-89	-99	197	-67	132
1L -3	9:46:00	2	1,500	342	-87	172	-191	379	-109	-91	-100	199	-67	132
1L -3	9:48:00	4	1,500	342	-87	172	-192	381	-110	-92	-101	201	-68	135
1L -3	9:52:00	8	1,500	342	-87	172	-192	381	-111	-92	-102	202	-69	137
1L -4	9:55:00	1	2,000	455	-109	217	-249	495	-140	-119	-129	257	-97	192
1L -4	9:56:00	2	2,000	455	-109	217	-252	500	-140	-119	-129	257	-97	192
1L -4	9:58:00	4	2,000	455	-110	219	-252	500	-140	-119	-129	257	-97	192
1L -4	10:02:00	8	2,000	455	-130	259	-305	607	-171	-144	-157	313	-122	242
1L -5	10:05:00	1	2,500	568	-134	266	-323	641	-173	-149	-161	320	-128	254
1L -5	10:06:00	2	2,500	568	-134	266	-325	646	-172	-149	-161	319	-128	254
1L -5	10:08:00	4	2,500	568	-135	268	-328	651	-175	-150	-162	323	-129	257
1L -5	10:12:00	8	2,500	568	-136	271	-342	679	-181	-154	-167	333	-132	262
1L -6	10:15:00	1	3,000	681	-161	321	-437	867	-216	-178	-197	391	-157	312
1L -6	10:16:00	2	3,000	681	-161	321	-437	867	-216	-178	-197	391	-157	312
1L -6	10:18:00	4	3,000	681	-161	321	-442	877	-218	-178	-198	393	-157	312
1L -6	10:23:30	9	3,000	681	-153	303	-402	798	-203	-163	-183	364	-147	292
1U -1	10:26:00	1	2,300	523	-150	298	-392	778	-197	-159	-178	354	-142	282
1U -1	10:27:00	2	2,300	523	-149	296	-390	775	-196	-158	-177	351	-142	282
1U -1	10:28:00	3	2,300	523	-150	298	-390	775	-195	-158	-176	350	-141	279
1U -1	10:29:00	4	2,300	523	-131	261	-328	651	-166	-138	-152	301	-126	249
1U -2	10:31:30	1	1,600	365	-130	258	-320	636	-161	-134	-147	293	-122	242
1U -2	10:32:30	2	1,600	365	-130	258	-319	634	-161	-135	-148	294	-122	242
1U -2	10:33:30	3	1,600	365	-130	258	-318	631	-161	-135	-148	294	-122	242
1U -2	10:34:30	4	1,600	365	-105	209	-235	468	-121	-109	-115	228	-98	195
1U -3	10:36:00	1	900	207	-104	206	-235	468	-121	-110	-115	229	-98	195
1U -3	10:37:00	2	900	207	-105	209	-237	470	-121	-109	-115	228	-98	195
1U -3	10:38:00	3	900	207	-105	209	-237	470	-121	-111	-116	231	-98	195
1U -3	10:39:00	4	900	207	-75	149	-122	242	-75	-79	-77	152	-68	135
1U -4	10:41:00	1	250	60	-56	112	-77	153	-47	-59	-53	105	-49	97
1U -4	10:42:00	2	250	60	-56	112	-76	150	-46	-57	-52	103	-48	95
1U -4	10:43:00	3	250	60	-58	115	-84	167	-51	-59	-55	109	-51	102
1U -4	10:52:00	12	250	60	-58	115	-84	167	-51	-59	-55	109	-51	102
2L -1	10:54:00	1	1,500	342	-46	91	-180	357	-79	-51	-65	130	-49	97
2L -1	10:55:00	2	1,500	342	-46	90	-181	359	-79	-51	-65	129	-49	97
2L -1	10:56:00	3	1,500	342	-46	90	-183	364	-79	-51	-65	129	-49	97
2L -1	10:57:00	4	1,500	342	-75	150	-279	555	-131	-90	-111	220	-85	170
2L -2	11:00:00	1	3,000	681	-105	209	-369	733	-180	-125	-153	303	-117	232
2L -2	11:01:00	2	3,000	681	-108	214	-372	738	-180	-125	-153	303	-118	234
2L -2	11:02:00	3	3,000	681	-109	216	-374	743	-180	-125	-153	303	-118	234
2L -2	11:03:00	4	3,000	681	-129	256	-429	852	-213	-148	-181	359	-146	289
2L -3	11:05:00	1	3,500	793	-130	258	-445	884	-213	-149	-181	360	-151	299
2L -3	11:06:00	2	3,500	793	-130	258	-449	892	-213	-149	-181	360	-151	299
2L -3	11:08:00	4	3,500	793	-130	258	-454	902	-216	-151	-183	364	-153	304
2L -3	11:12:00	8	3,500	793	-150	298	-512	1016	-249	-172	-210	418	-181	359
2L -4	11:14:30	1	4,000	906	-155	308	-534	1061	-250	-176	-213	423	-187	371
2L -4	11:15:30	2	4,000	906	-155	308	-539	1071	-252	-176	-214	425	-188	374
2L -4	11:17:30	4	4,000	906	-155	308	-544	1081	-254	-176	-215	426	-188	374
2L -4	11:21:30	8	4,000	906	-175	348	-599	1190	-282	-196	-239	475	-212	421
2L -5	11:24:00	1	4,500	1,019	-181	360	-633	1257	-283	-210	-247	490	-223	444
2L -5	11:25:00	2	4,500	1,019	-183	363	-639	1269	-283	-211	-247	491	-223	444
2L -5	11:27:00	4	4,500	1,019	-185	368	-644	1279	-285	-211	-248	492	-226	449
2L -5	11:31:00	8	4,500	1,019	-195	387	-679	1348	-300	-226	-263	522	-241	479
2L -6	11:35:30	1	5,000	1,132	-209	415	-726	1442	-310	-241	-275	547	-252	501
2L -6	11:36:30	2	5,000	1,132	-210	417	-734	1457	-313	-241	-277	550	-254	504
2L -6	11:38:30	4	5,000	1,132	-210	417	-736	1462	-309	-241	-275	547	-251	499
2L -6	11:42:30	8	5,000	1,132	-215	427	-758	1505	-318	-251	-285	565	-256	509
2L -7	11:53:00	0	5,500	1,244	-235	466	-816	1621	-367	-236	-301	598	-251	499
2L -7	11:54:00	1	5,500	1,244	-236	469	-818	1625	-369	-231	-300	596	-251	499
2L -7	11:55:00	2	5,500	1,244	-230	456	-798	1586	-353	-218	-286	567	-236	469
2U -1	11:59:30	1	4,100	929	-210	417	-703	1397	-318	-191	-254	505	-207	411
2U -1	12:00:30	2	4,100	929	-210	417	-700	1390	-317	-189	-253	503	-205	406
2U -1	12:01:30	3	4,100	929	-210	417	-698	1387	-313	-186	-249	495	-203	404
2U -1	12:02:30	4	4,100	929	-175	347	-569	1129	-256	-151	-203	403	-169	337
2U -2	12:07:30	1	2,500	568	-155	307	-499	990	-225	-134	-180	357	-151	299
2U -2	12:08:30	2	2,500	568	-155	307	-498	990	-227	-134	-180	358	-151	299
2U -2	12:09:30	3	2,500	568	-154	307	-498	990	-225	-134	-180	357	-149	297
2U -2	12:10:30	4	2,500	568	-112	222	-348	692	-158	-94	-126	250	-107	212
2U -3	12:13:00	1	1,500	342	-109	217	-338	672	-153	-94	-123	245	-104	207
2U -3	12:14:00	2	1,500	342	-108	215	-338	672	-153	-93	-123	244	-104	207
2U -3	12:15:00	3	1,500	342	-107	212	-338	672	-153	-92	-122	243	-104	207
2U -3	12:16:00	4	1,500	342	-89	178	-266	528	-124	-70	-97	193	-84	167
2U -4	12:18:30	1	900	207	-76	150	-228	454	-108	-65	-86	172	-70	140
2U -4	12:19:30	2	900	207	-76	150	-230	456	-106	-65	-86	171	-70	140
2U -4	12:20:30	3	900	207	-74	148	-223	444	-105	-65	-85	169	-70	140
2U -4	12:21:30	4	900	207	-74	148	-218	434	-103	-64	-83	165	-69	137
2U -5	12:26:00	1	500	117	-49	98	-123	245	-68	-45	-56	112	-45	90
2U -5	12:27:00	2	500	117	-49	98	-127	252	-68	-45	-56	112	-46	92
2U -5	12:28:00	3	500	117	-49	98	-128	255	-68	-45	-56	112	-48	95
2U -5	12:29:00	4	500	117	-14	28	7	-13	-25	-18	-21	42	-15	30
2U -6	12:31:00	1	0	0	-11	21	29	-58	-15	-16	-16	31	-14	28
2U -6	12:32:00	2	0	0	-11	21	29	-58	-15	-16	-16	31	-14	28
2U -6	12:34:00	4	0	0	-11	21	29	-58	-15	-16	-16	31	-14	28
2U -6	12:38:00	8	0	0	-11	21	29	-58	-15	-16	-16	31	-14	28

TexDOT UT ADSC - TS-1

Austin, TX, 8/23/2012





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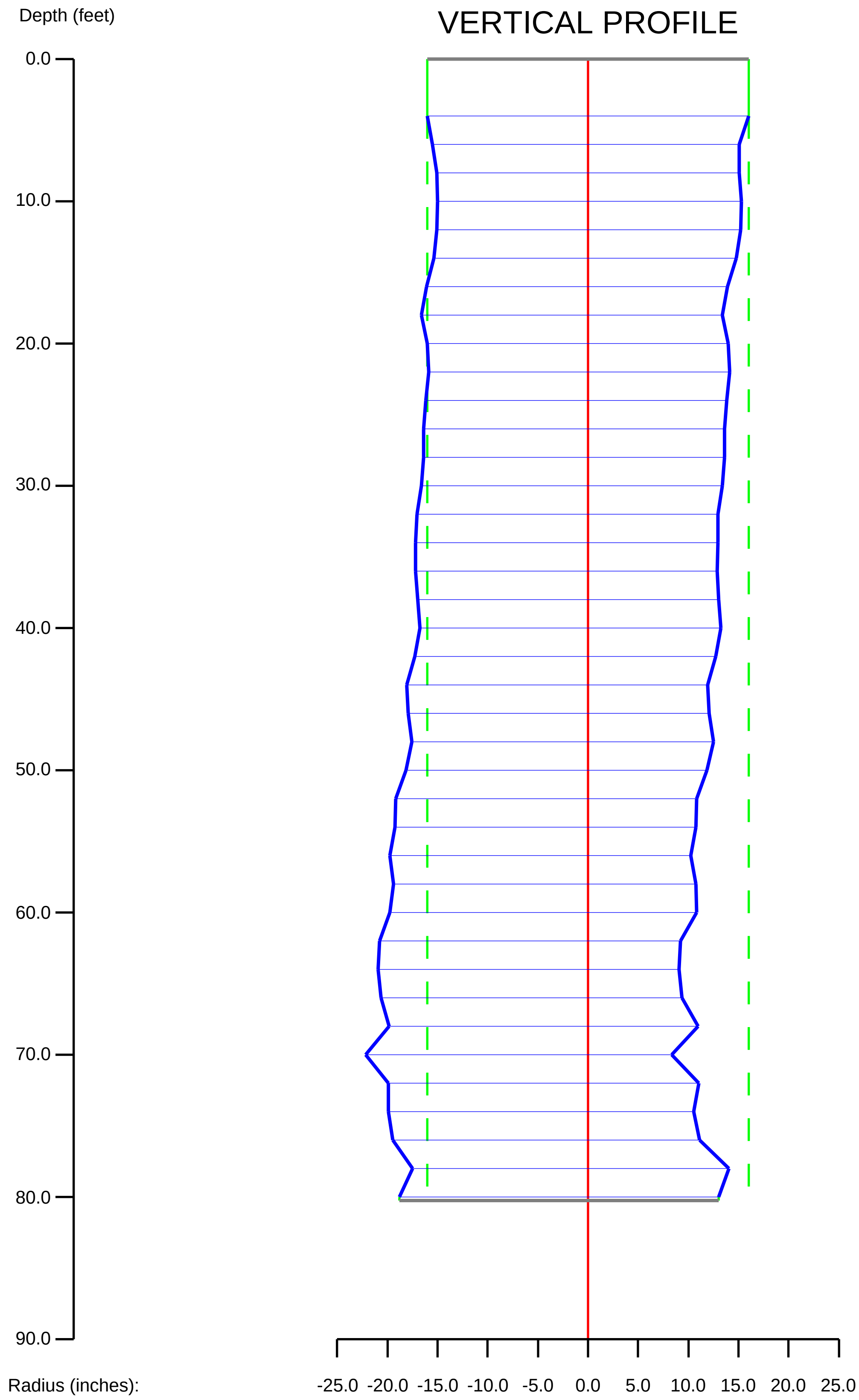
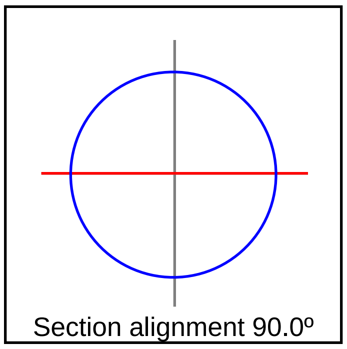
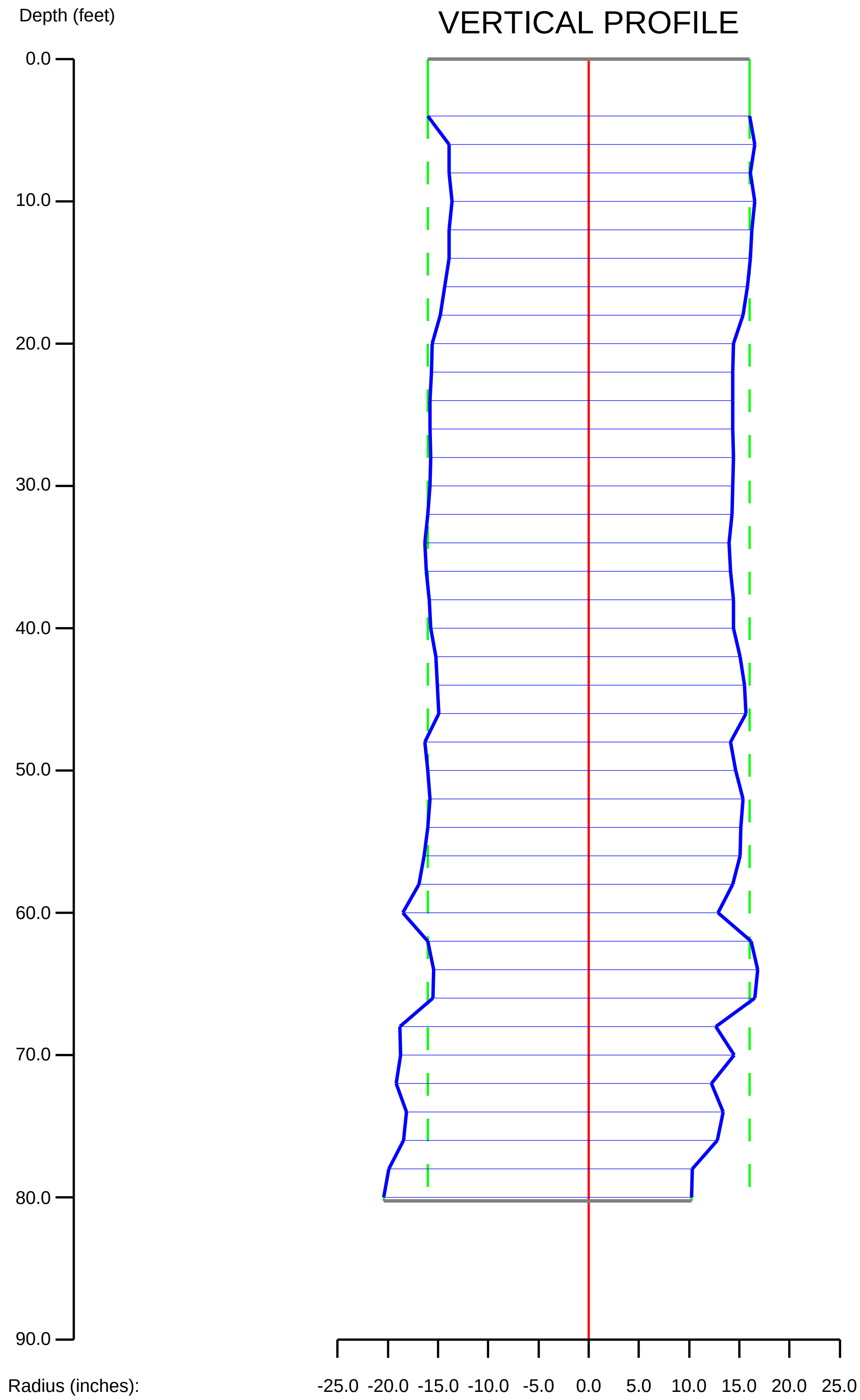


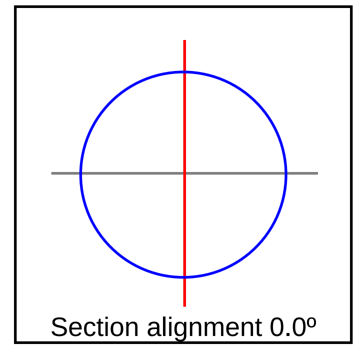


Project Number: 9981-1

TexDOT UT ADSC - TS-1

Austin, TX, 8/23/2012





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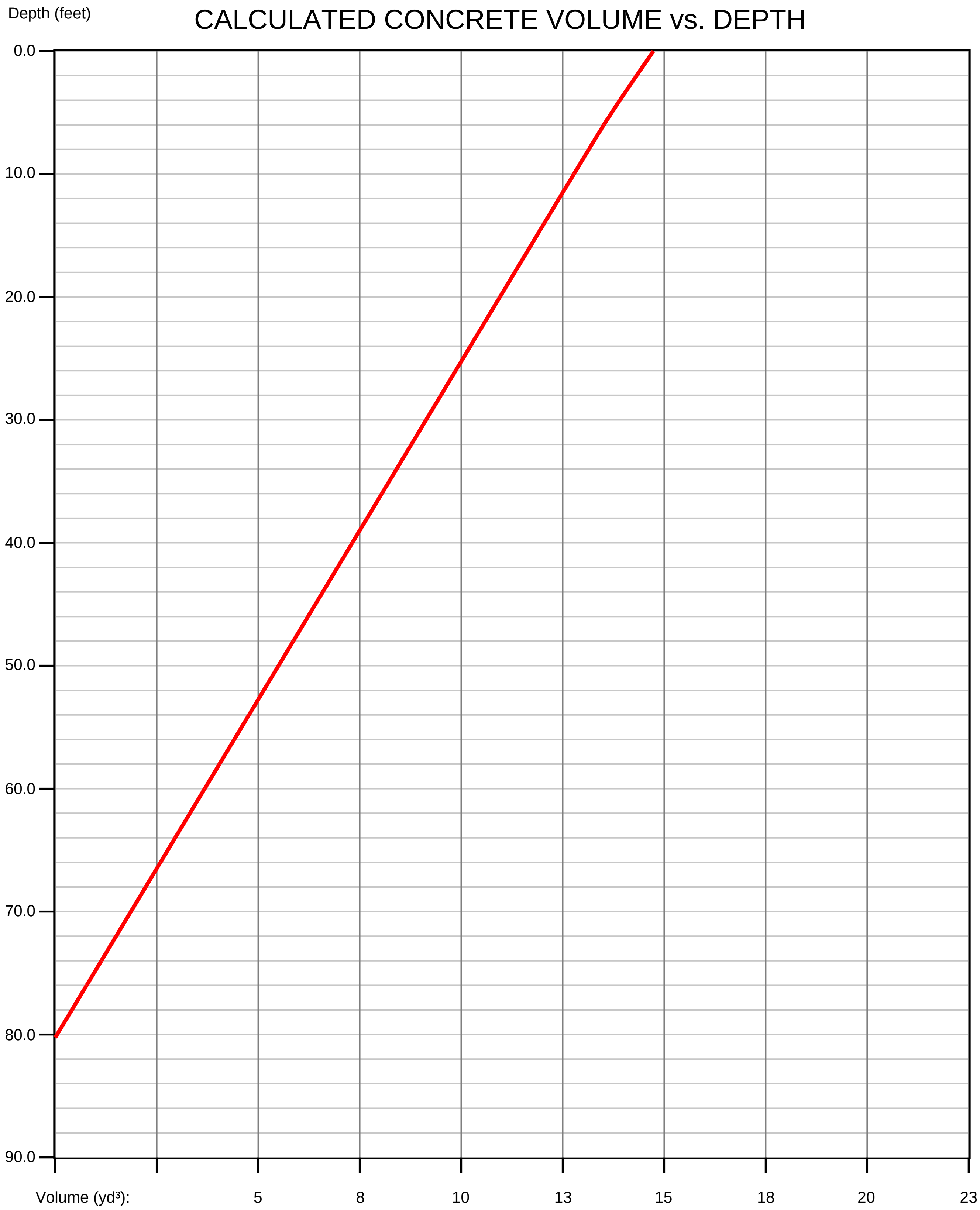
Austin, TX, 8/23/2012



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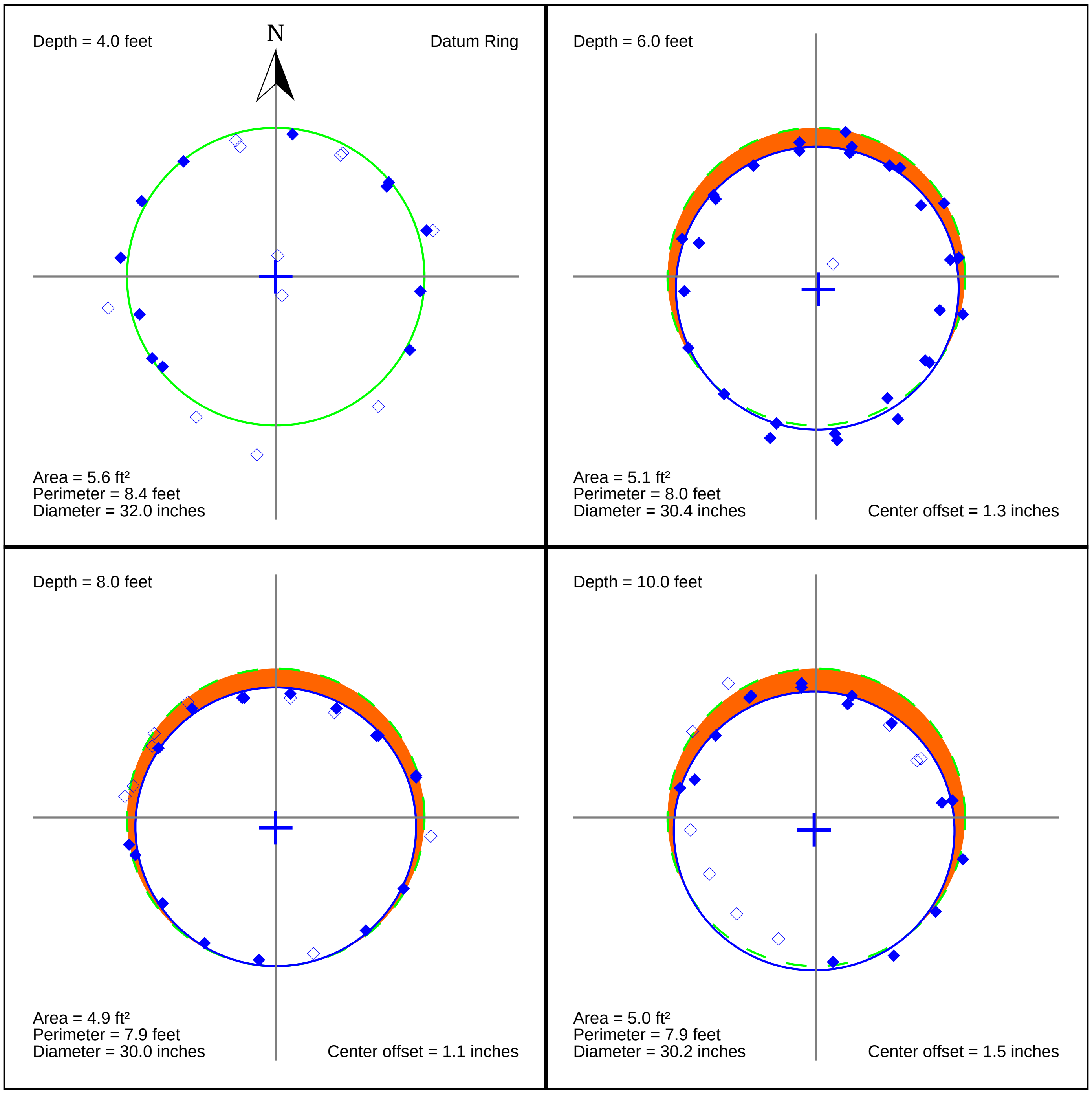
Austin, TX, 8/23/2012



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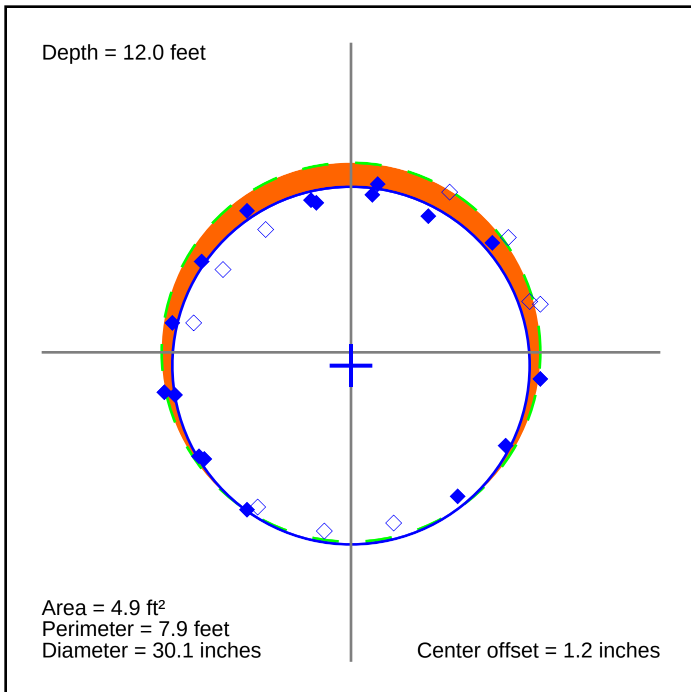
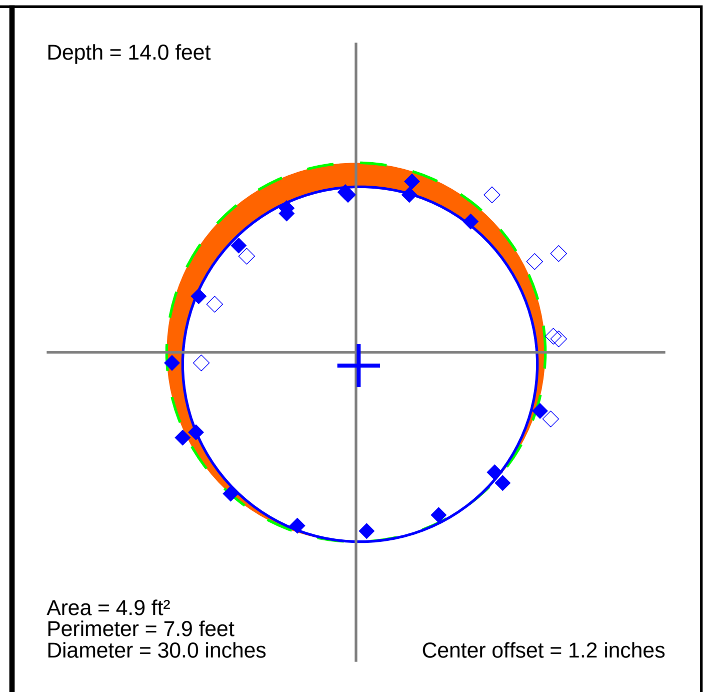
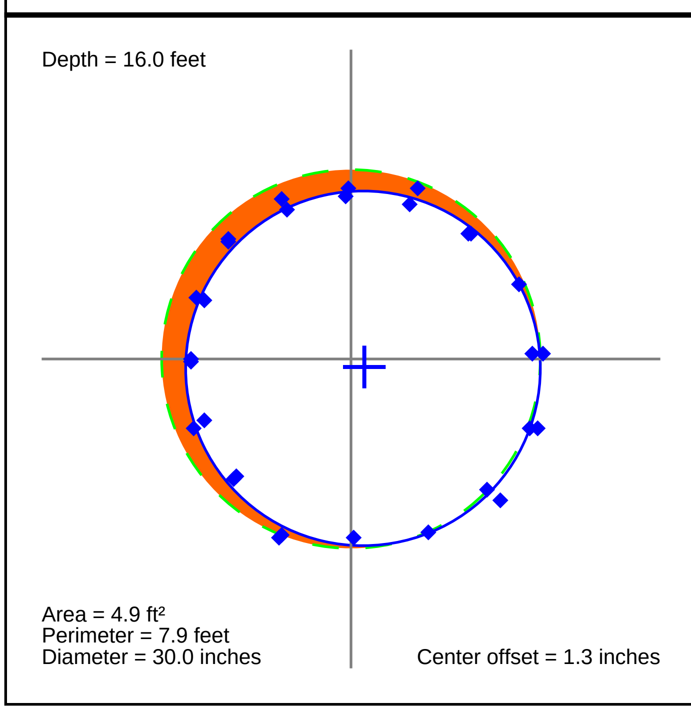
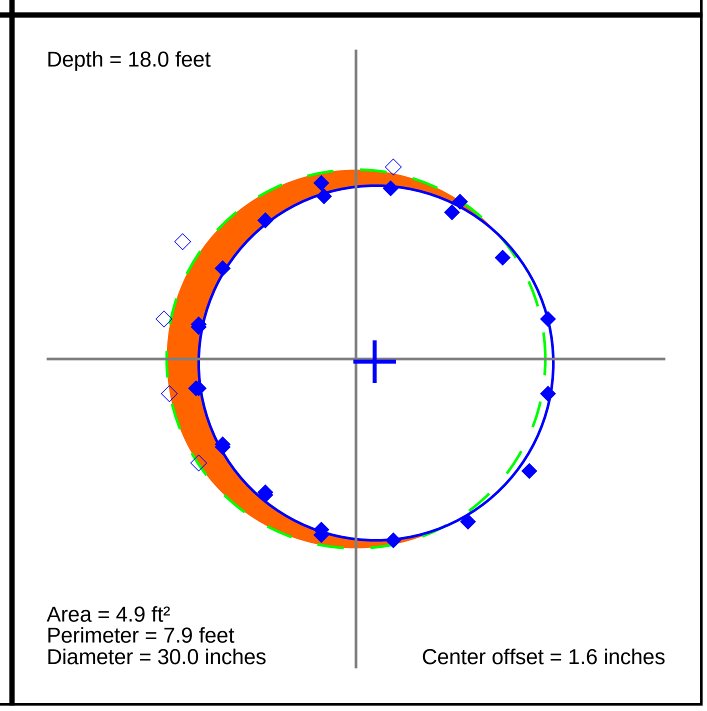
Austin, TX, 8/23/2012









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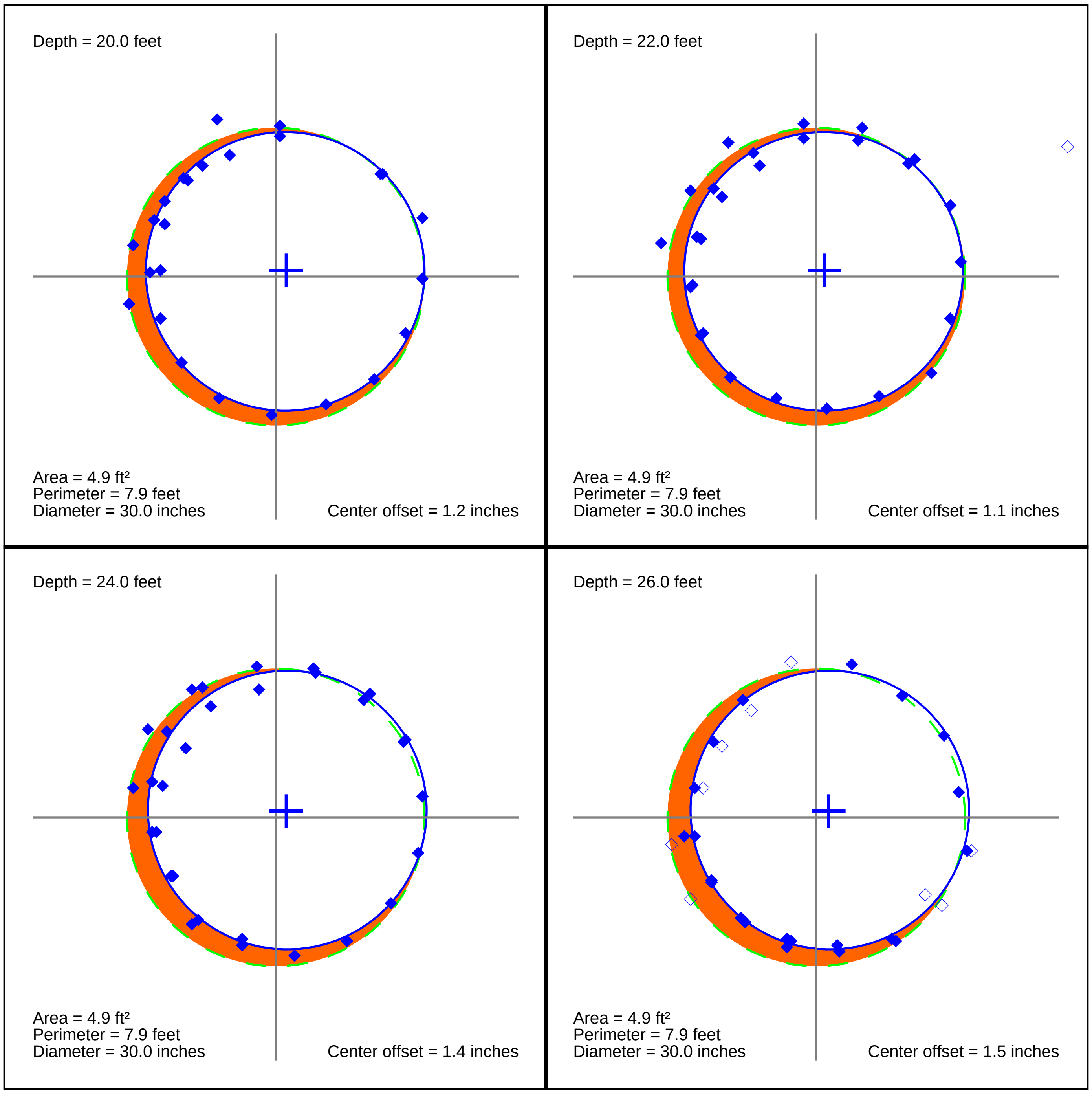
Austin, TX, 8/23/2012



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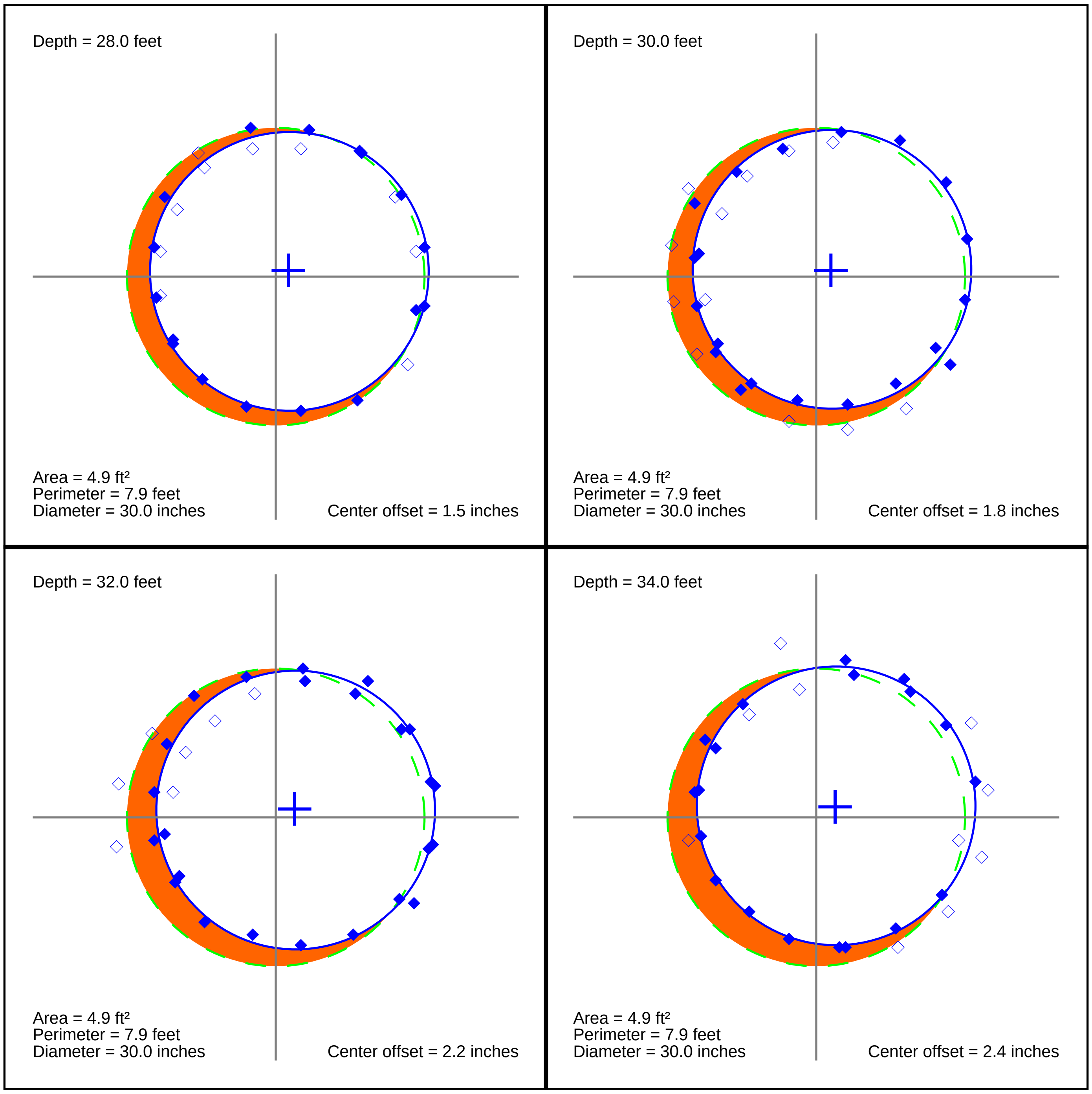

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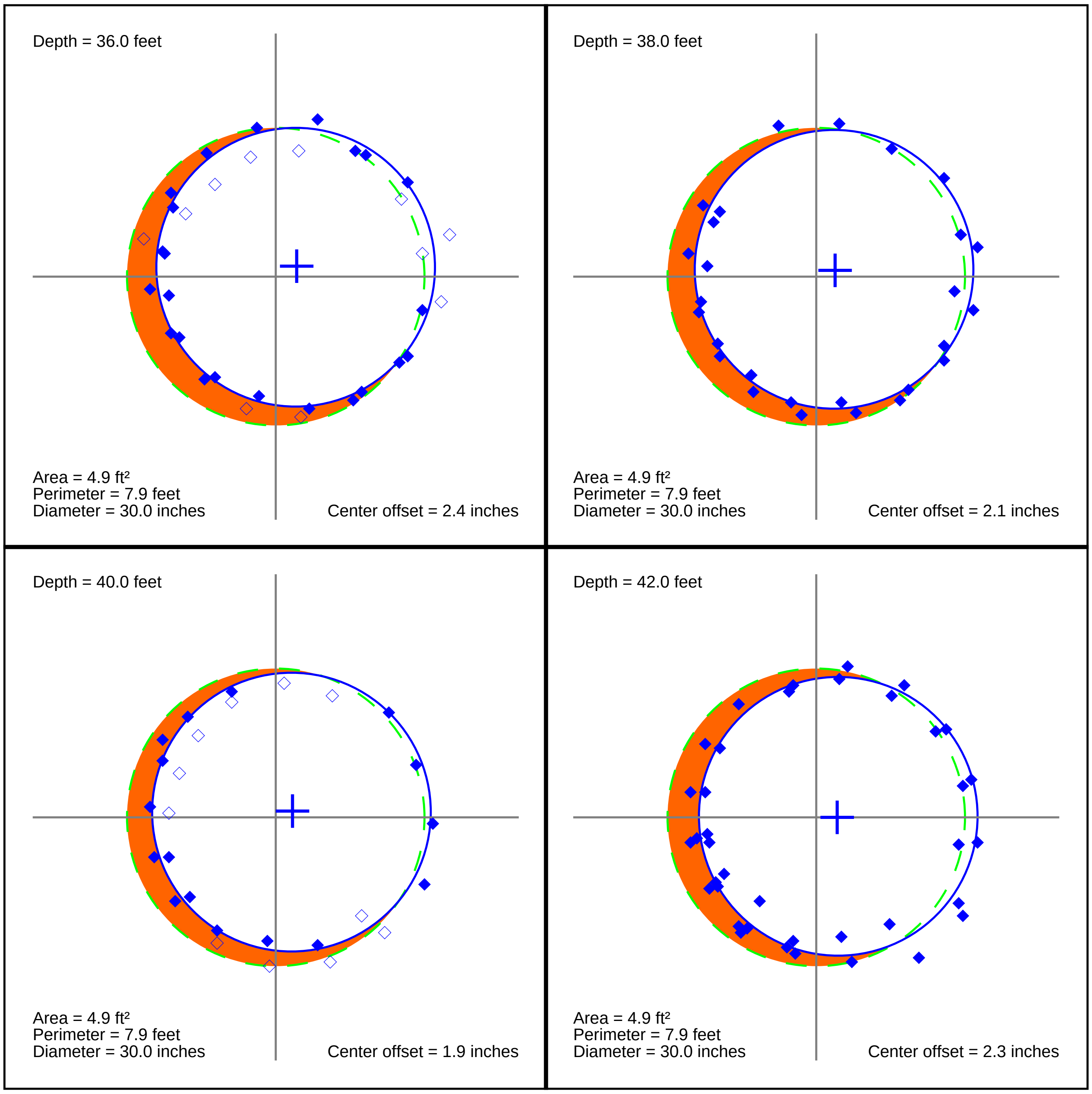

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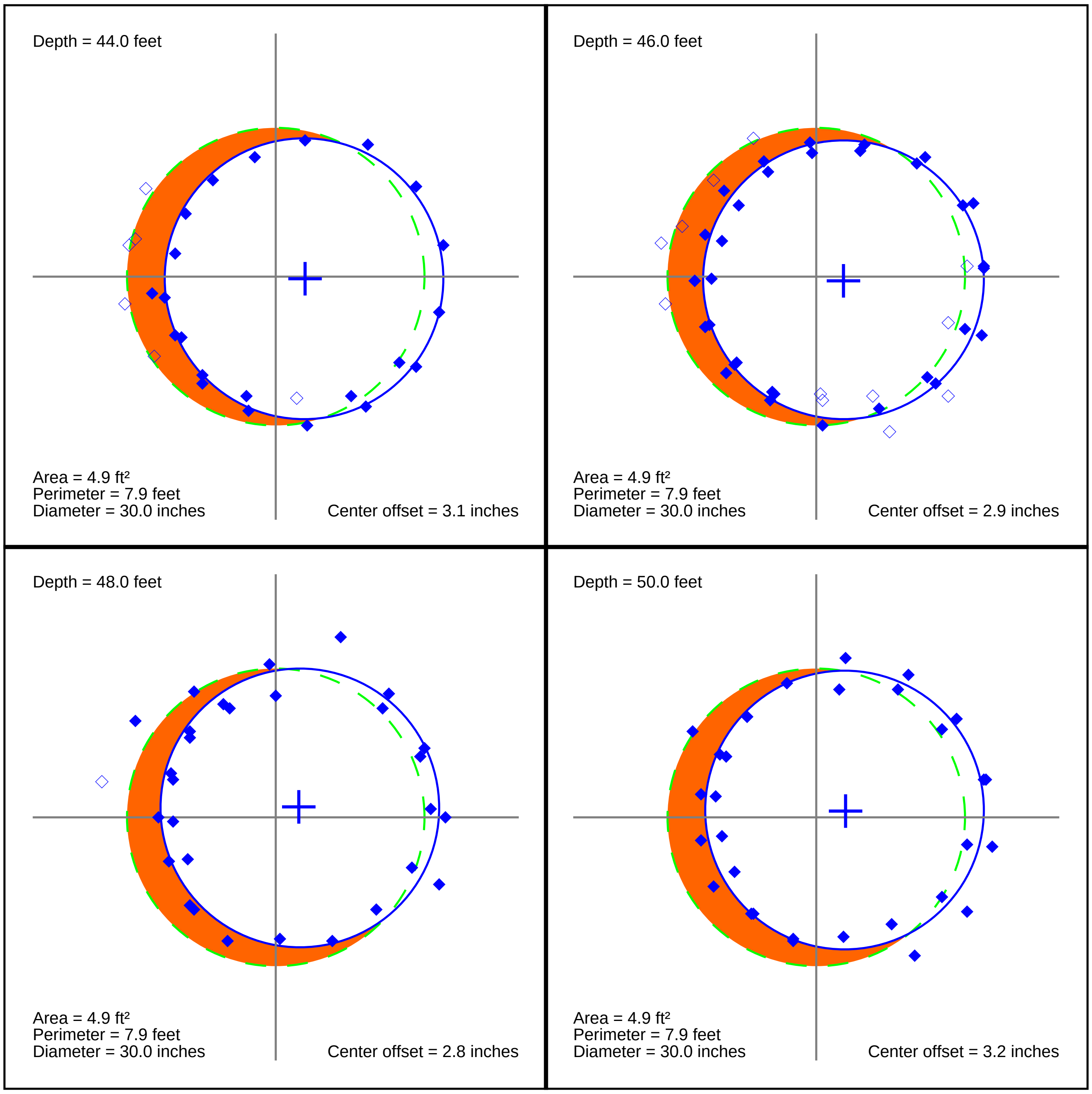

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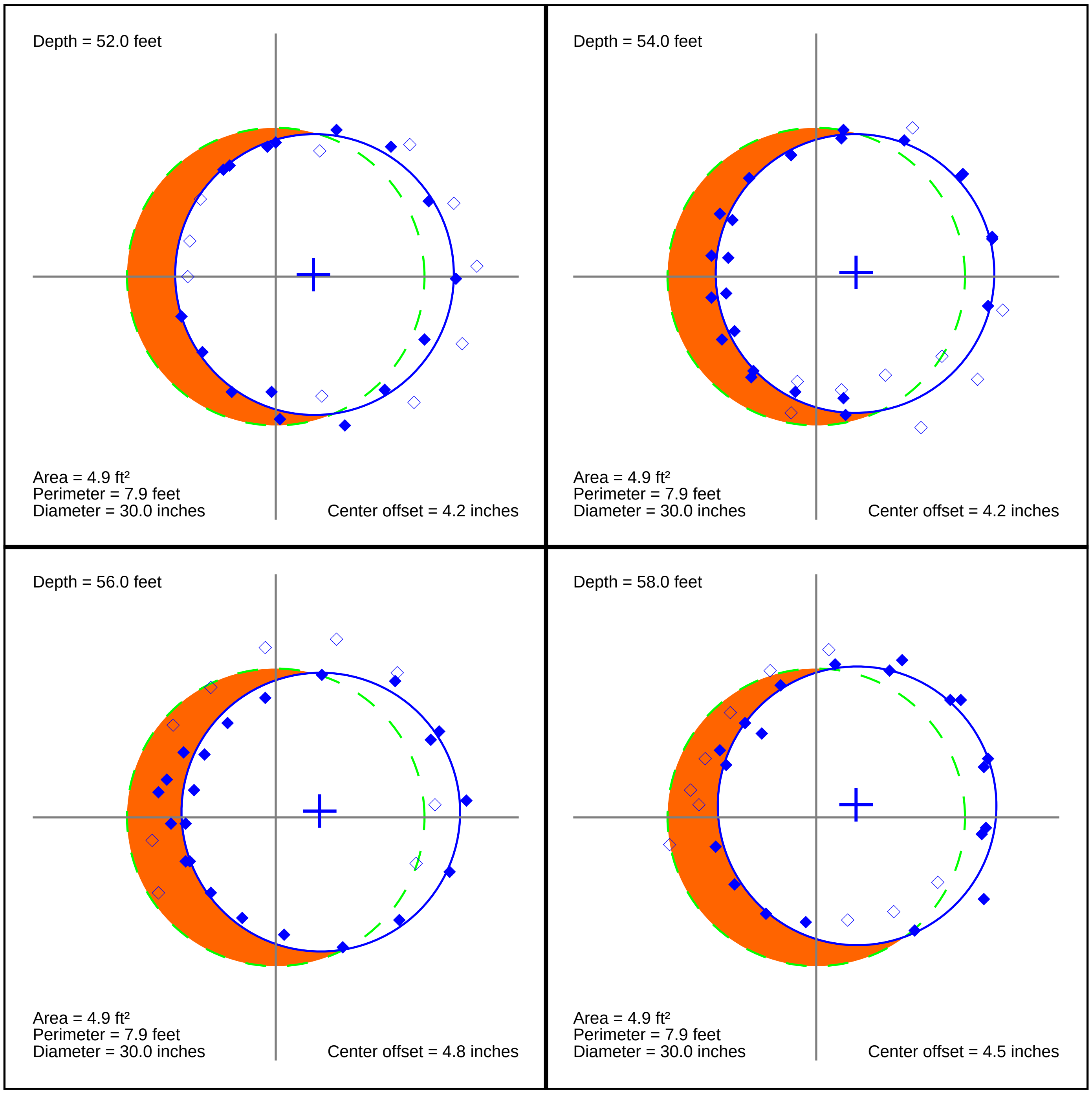
Austin, TX, 8/23/2012



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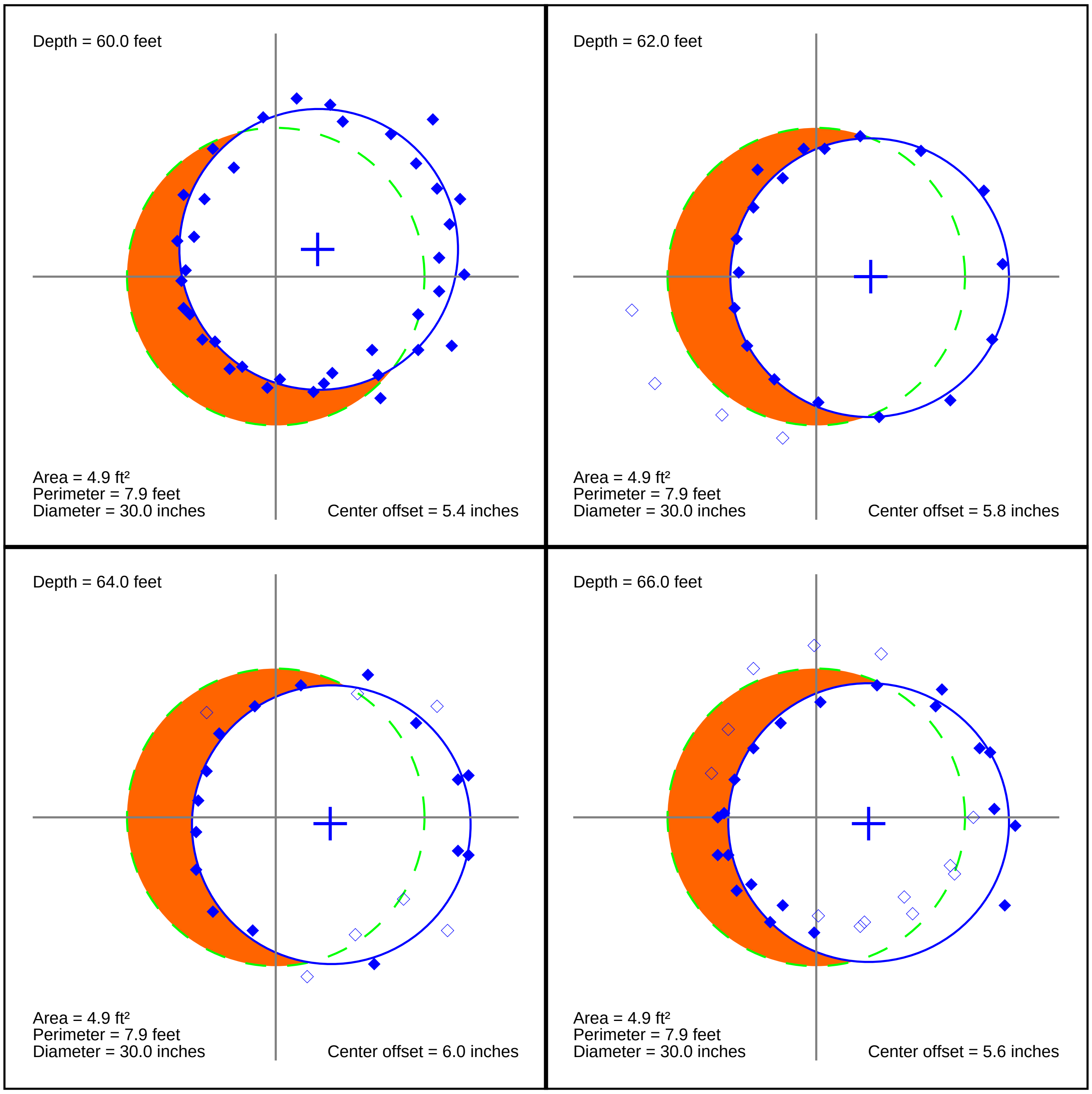

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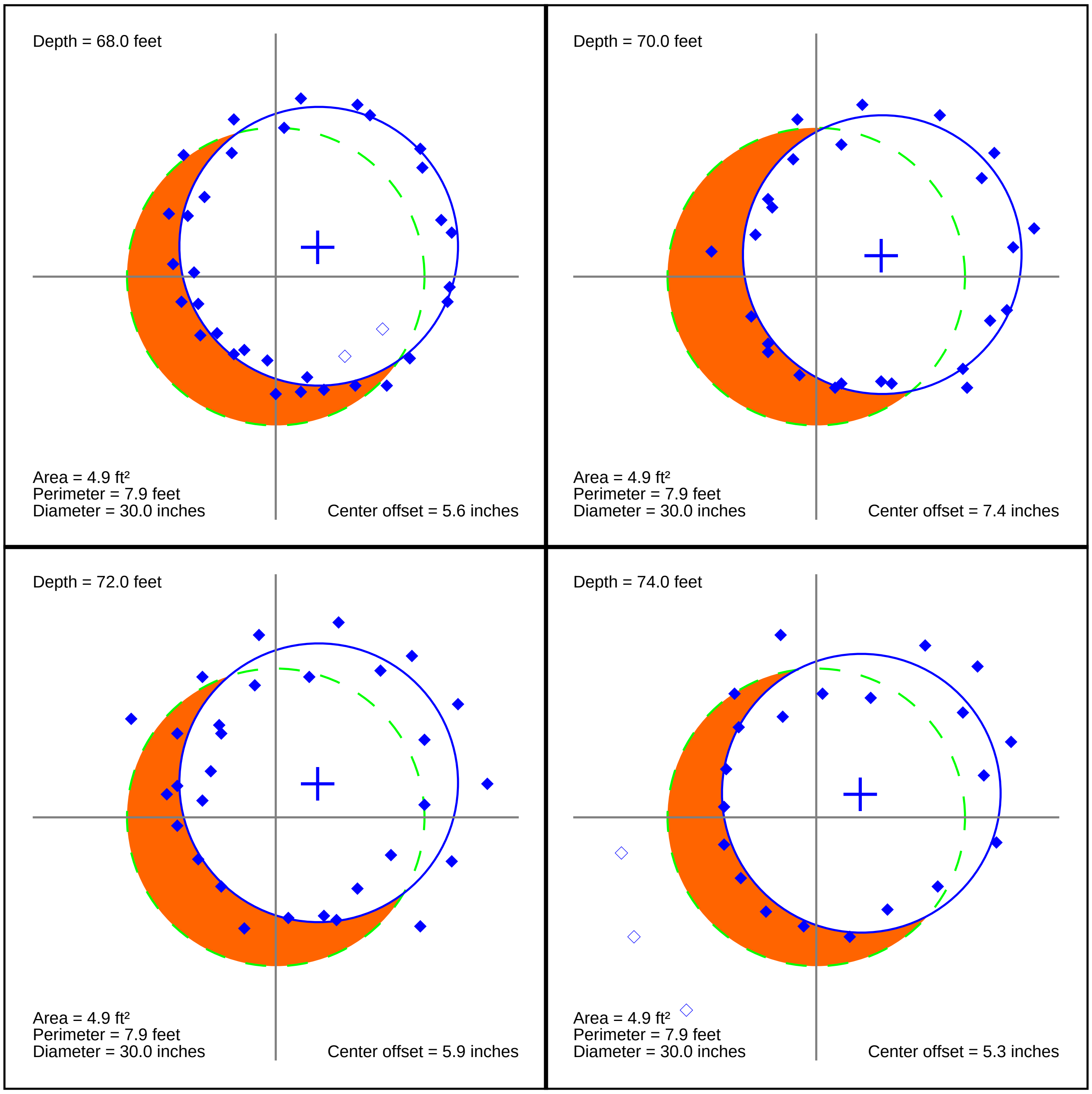

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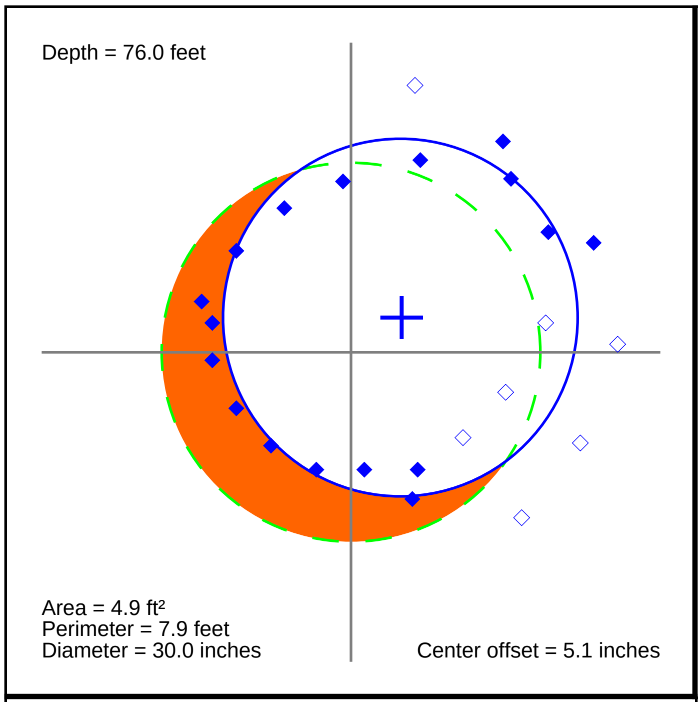
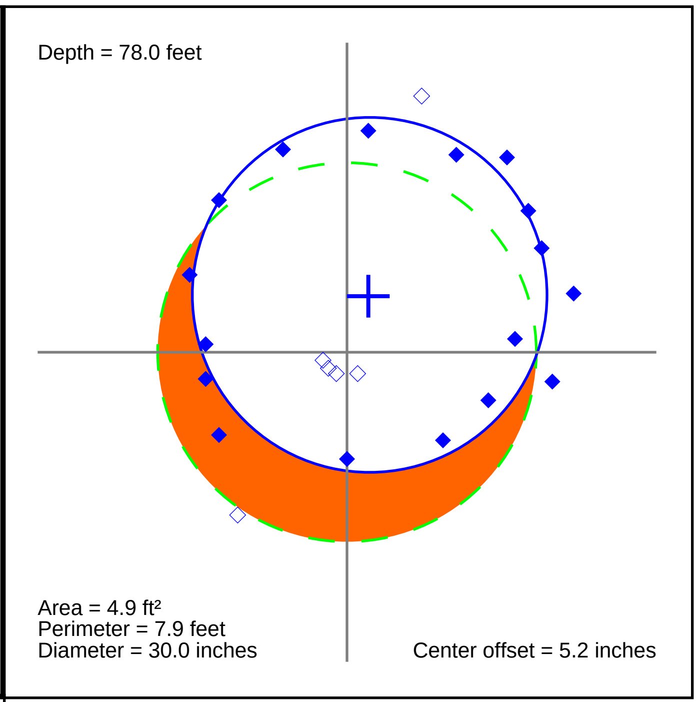
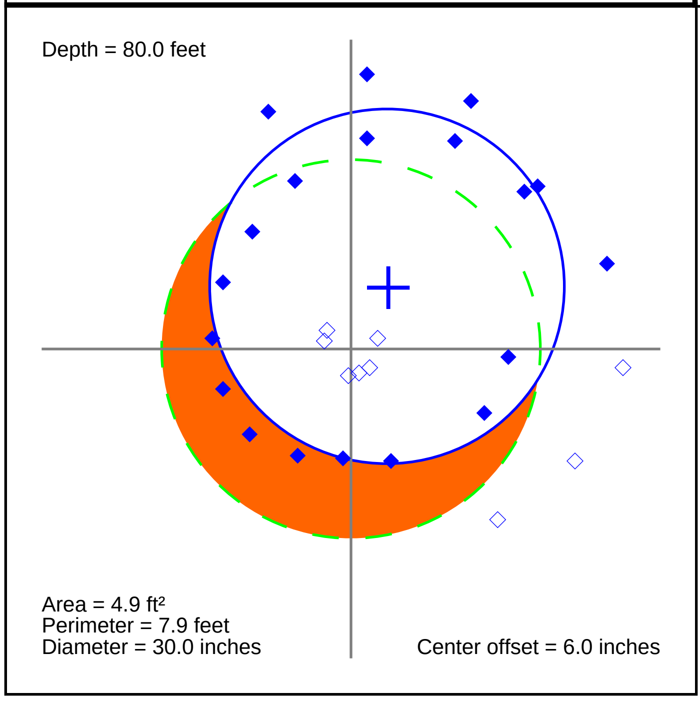






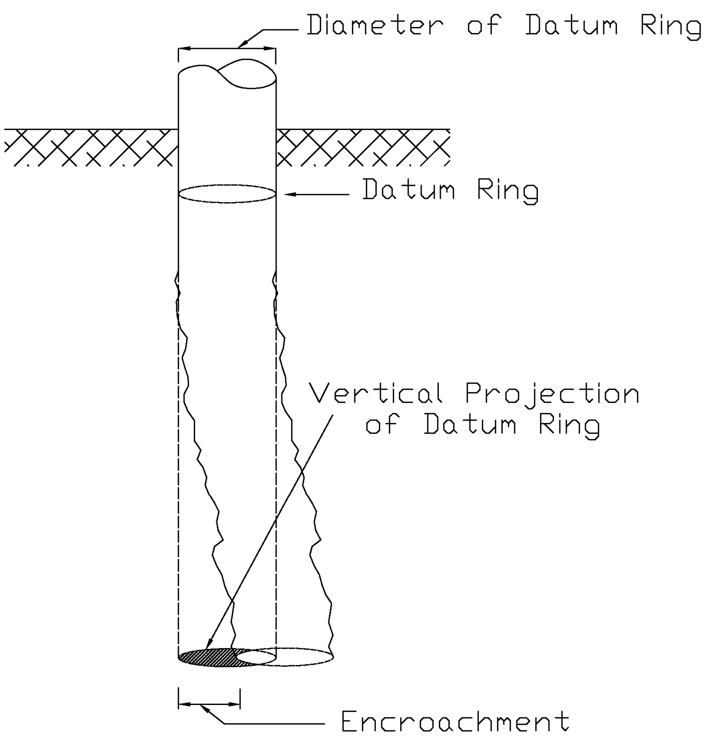
INTERPRETATION OF SONICALIPER FIELD DATA REPORT

General: The SoniCaliper is a profiling sonar device, specially adapted to function in drilling fluids. Each 360° pass generated with the SoniCaliper device produces up to one hundred twenty individual echo returns (profile data points). In the preceding figures (profile ring plots), the diamond points represent individual profile data points. A geometric shape is fitted to the data points using an iterative least-squares technique to approximate the cross-sectional profile of the shaft for verticality, perimeter area and volume calculations. Hollow diamonds designate points that are not used in the data fitting.

Deployment: The device is lowered into the shaft excavation in incremental depths. At each depth, a 360° sweep of the shaft wall is performed. The device is assumed to hang vertically in the shaft (any deviation from verticality can be noted using onboard pitch and roll sensors). Any twist in the device relative to its initial orientation is compensated by onboard compass and/or gyroscope sensors.

Calibration: Because the properties of drilling fluids vary widely, a calibration must be performed for each shaft to determine fluid wavespeed. This is done by selecting a profile ring of known diameter (usually, but not always the upper-most profile ring) as the “calibration ring”. The data analysis then back-calculates the fluid wavespeed based on the known diameter of this ring. The fluid wavespeed is assumed to be constant over the entire column of fluid depth.

Shaft Verticality: To determine shaft verticality, a profile ring (usually, but not always the calibration ring) is selected as the “datum ring”. The geometric centers of the datum ring and all other profile rings are compared. The “center offset” listed on the figures indicates the divergence of each profile ring center point from the datum ring center point. “Encroachment” is presented graphically as the shaded area representing the portion of the shaft wall which would encroach into the perfectly vertical projection of the datum ring to the depth in question. The maximum encroachment value for each profile ring is also given numerically. The user may choose to display computed values for the vertical inclination of the shaft between each ring and the datum ring, for both encroachment and center offset. Inclination may be expressed as a percentage or as a deviation:depth ratio.



Calipered Volume: The cross sectional area of each profile ring is determined and a cumulative volume for the calipered portion of the shaft is calculated. Note that this volume is a minimum.

REPORT OF CONCRETE CYLINDER COMPRESSION TESTS

Fugro Consultants, Inc.
8613 Cross Park Drive
Austin, Texas 78754
Phone (512) 977-1800
Fax (512) 973-9966

Project: UT O-Cell Install
Date Cast: 08/24/12
Job No.: 04.30121045
Cast By: Vann Corkill
Report Date: 9/21/2012

Mix Design Data Mix No. CXCD8B06

Concrete Supplier: TXI
Approved Uses: None

Location of Placement: Test Pier Hole #1
Truck No.: 7054
Ticket No.: 1468146
Time Batched: 0943
Time Placed: 1045

	Properties of Fresh Concrete	Specifications
Ambient Temp. (°F):	83	
Concrete Temp. (°F), ASTM 1064:	93	
Slump (inches), ASTM C143:	7.5	-- to --"
Air Content by Volumemetric Method (%), ASTM C173:	--	-- to --%
Air Content By Pressure Method (%), ASTM C231:	--	-- to --%
Plastic Unit Weight (pcf), ASTM C138:	--	
Water Added on Site, (gal):	--	

Laboratory Test Results

Specified Strength: 3,600 psi at 28 days

Laboratory No.	Date Tested	Age, Days	Diameter inches	Area sq in.	Total Load, lbs.	Compressive Strength, psi	Percent of Design	Fracture Type	
VC0824121045 A	8/30/2012	6	6.00	28.27	68,720	2,430	68%	-	**
VC0824121046 B	8/31/2012	7	6.00	28.27	68,810	2,430	68%	-	
VC0824121045 C	9/21/2012	28	6.00	28.27	134,680	4,760	132%	6	
VC0824121045 D	9/21/2012	28	6.00	28.27	136,060	4,810	134%	5	
VC0824121045 E	10/19/2012	56	6.00	28.27		-	-	-	

NOTES:

1. Cylinders are standard 6 in. dia. by 12 in. height, molded in accordance with ASTM C31, delete Para.10.1.2
2. Fresh concrete and molded specimen were tested in accordance with ASTM C39, C172, and C1231.
3. Fracture Types: 1) cone, 2) cone & split, 3) columnar, 4) diagonal, 5) corner fracture, 6) multiple corner fractures
4. Batch plant inspection not performed.

** Denotes 7-Day test did not reach 70% of the Specied Strength.

DISTRIBUTION:

Submitted by: Fugro Consultants, Inc.
TBPE Firm Registration No. 299

STATE OF TEXAS
JOHN S. LANDWERMEYER
79751
LICENSED
PROFESSIONAL ENGINEER

9/25/12

John S. Landwermeyer, P.E.

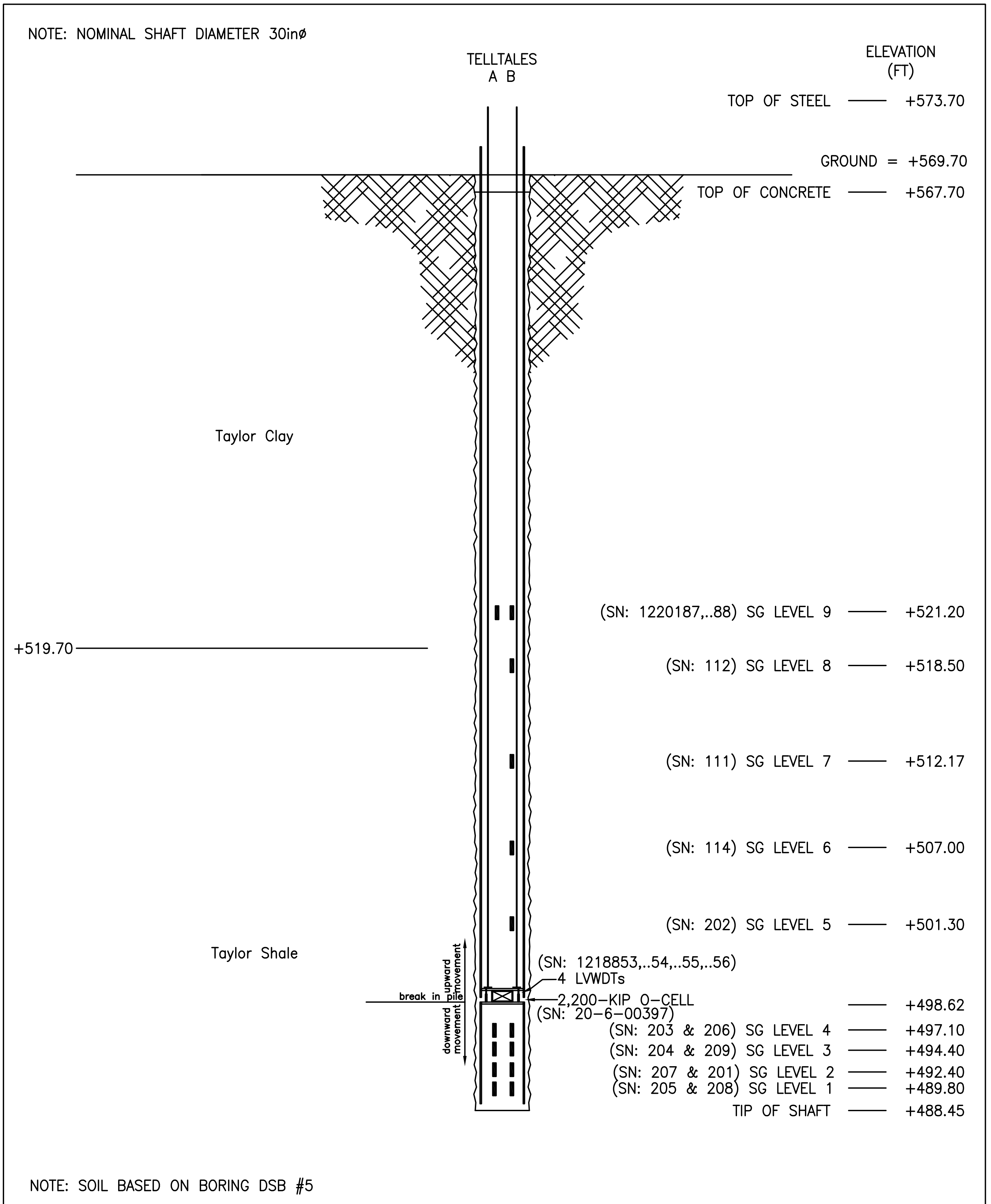
THE ABOVE TEST RESULTS APPLY ONLY TO THE ITEMS TESTED.
THIS REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL WITHOUT THE APPROVAL OF FUGRO.

Appendix C: Test Shaft #2

TABLE A: SUMMARY OF DIMENSIONS, ELEVATIONS, AREAS & PROPERTIES FOR ANALYSIS PURPOSES

Shaft: (TS 2, TexDOT - UT - ADSC Research, Austin, TX, LT-9981-2)		
Nominal shaft diameter: EL +567.2 ft to +486.95 ft	=	30 inches
O-cell size: (Serial no.: 20-6-00397)	=	20 inches
Length of concrete from break at base of cell to tip	=	10.2 feet
Shaft shear area from break at base of cell to tip	=	79.9 $feet^2$
Shaft end area	=	4.9 $feet^2$
Weight of shaft from break at base of cell to top of shaft	=	52.1 kips
Estimated shaft unit stiffness: EL +567.2 ft to +486.95 ft	=	2,600,000 kips
Elevation of top of shaft concrete	=	+567.70 feet
Elevation of top of ground surface	=	+569.70 feet
Elevation of break at base of O-cell[1]	=	+498.62 feet
Elevation of shaft tip	=	+488.45 feet
Water elevation was below tip		
Casings:		
NA		
Measured Compression Zones:		
Elevation of top of zone	=	+567.70 feet
Elevation of bottom of telltale (bottom of zone)	=	+499.92 feet
Strain Gages:		
Elevation of strain gage Level 8	=	+518.50 feet
Elevation of strain gage Level 7	=	+512.70 feet
Elevation of strain gage Level 6	=	+507.00 feet
Elevation of strain gage Level 5	=	+501.00 feet
Elevation of strain gage Level 4	=	+497.10 feet
Elevation of strain gage Level 3	=	+494.40 feet
Elevation of strain gage Level 2	=	+492.40 feet
Elevation of strain gage Level 1	=	+489.80 feet
Elevation of strain gage Level 1' (Loadtest SG)	=	+521.47 feet
Miscellaneous:		
Concrete strength	=	3490 psi
Top plate diameter	=	24.0 inches
Top plate thickness	=	2.0 inches
Bottom plate diameter	=	24.0 inches
Bottom plate thickness	=	2.0 inches
Reinforcement	=	C-4 Channel - 2 vertical pieces
LVWDT radii at 0, 60,180, 240 degrees orientation	=	11.0 inches

[1]The break between upward and downward movement at the O-cell assembly

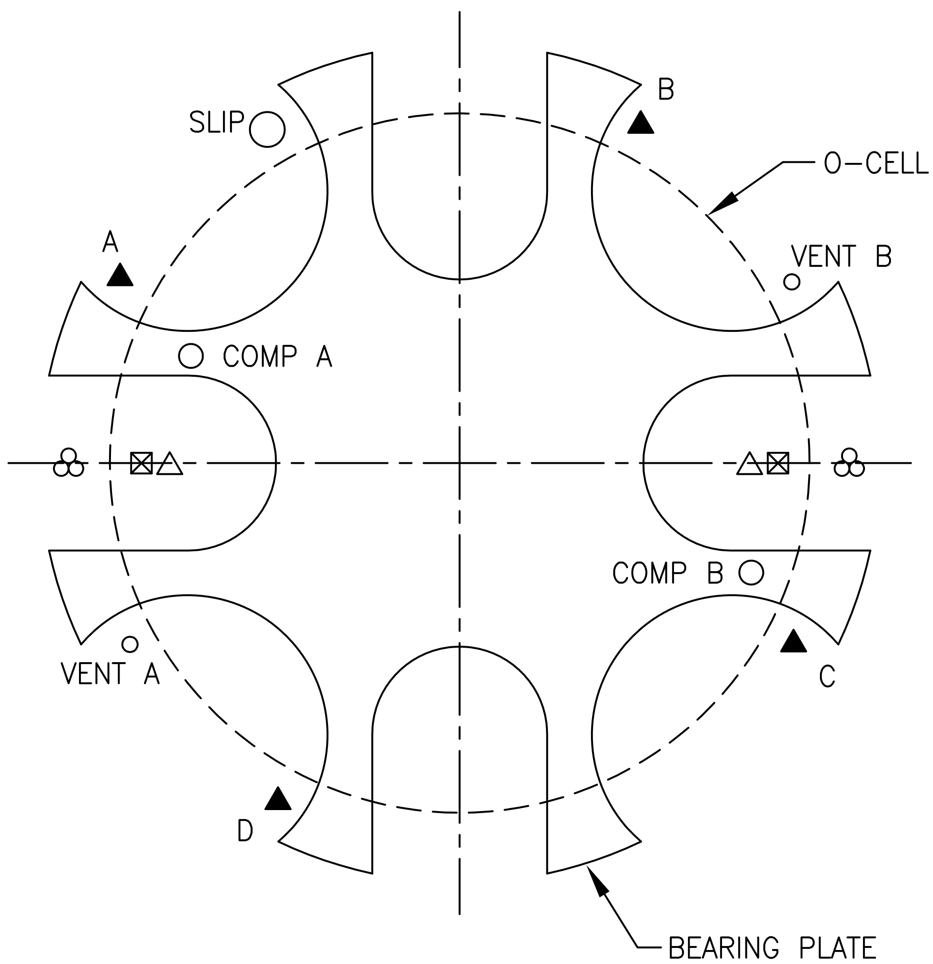


LOADTEST
www.LOADTEST.com

2631-D NW 41st St.
Gainesville, FL, 32606
Phone: 800-368-1138
Fax: 352-378-3934

AS BUILT SECTION OF TEST SHAFT
TEXDOT - UT - ADSC RESEARCH - AUSTIN, TX

DWN BY: RCS	DATE: 15 Jun 2012	CHECKED BY:	LT-9981-2
REVISED BY: AJS	DATE: 26 Sep 2012	SCALE: NTS	**FIGURE A**



LEGEND:

STRAIN GAGE	△
LVWDT	▲
TELLTALE	○
VENT PIPE	□
HYDRAULIC HOSES	⊠
CABLE BUNDLE	

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INSTRUMENTATION LAYOUT

TEXDOT – UT – ADSC RESEARCH – AUSTIN, TX

DWN BY: RCS	DATE: 15 Jun 2012	CHECKED BY:	9981 – 2
REVISED BY: CEK	DATE: 18 Sept 2012	SCALE: NTS	**FIGURE B**

Osterberg Cell Load vs.Displacement Plots

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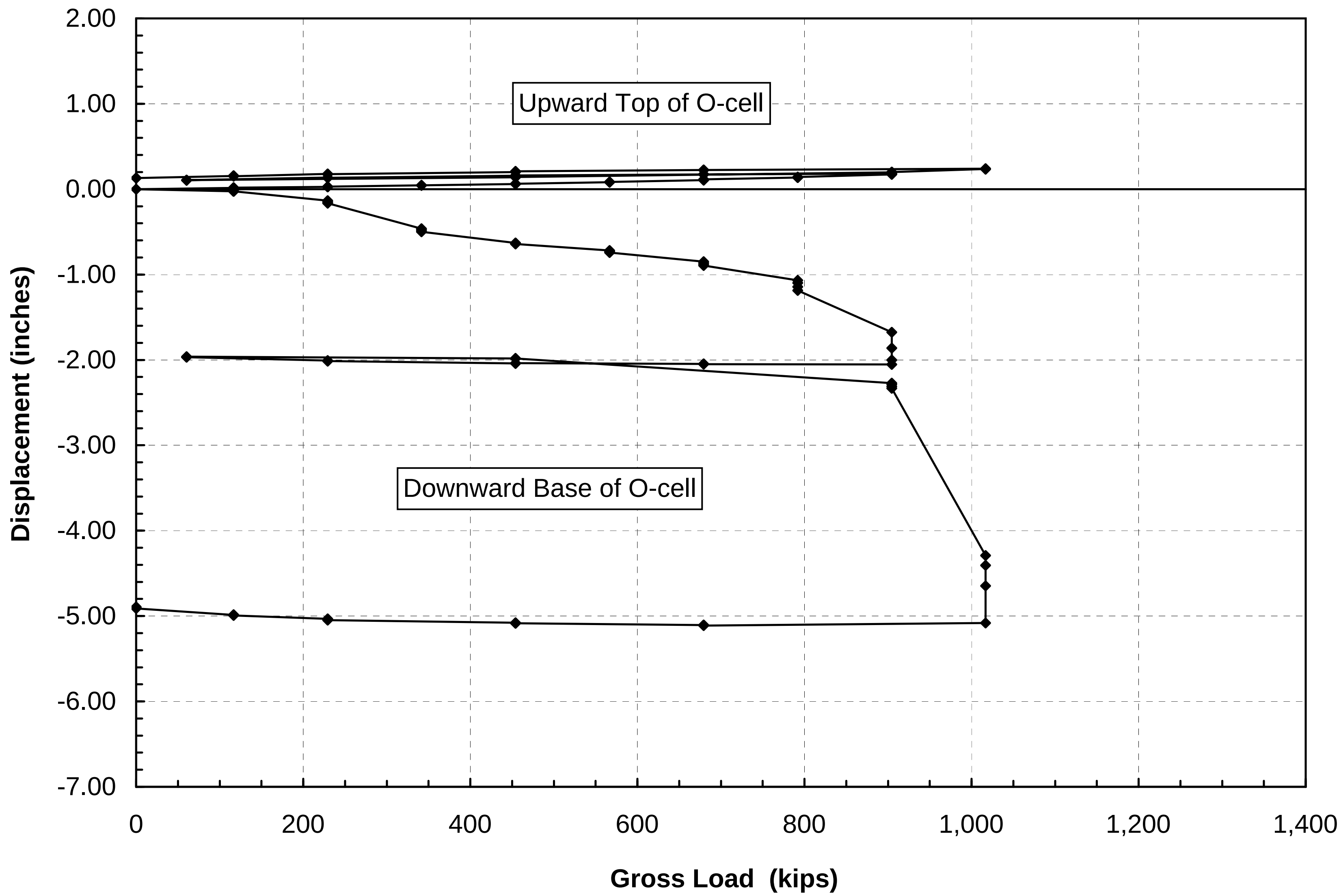

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Figure 1A of 8

Osterberg Cell Load vs.Displacement Plots

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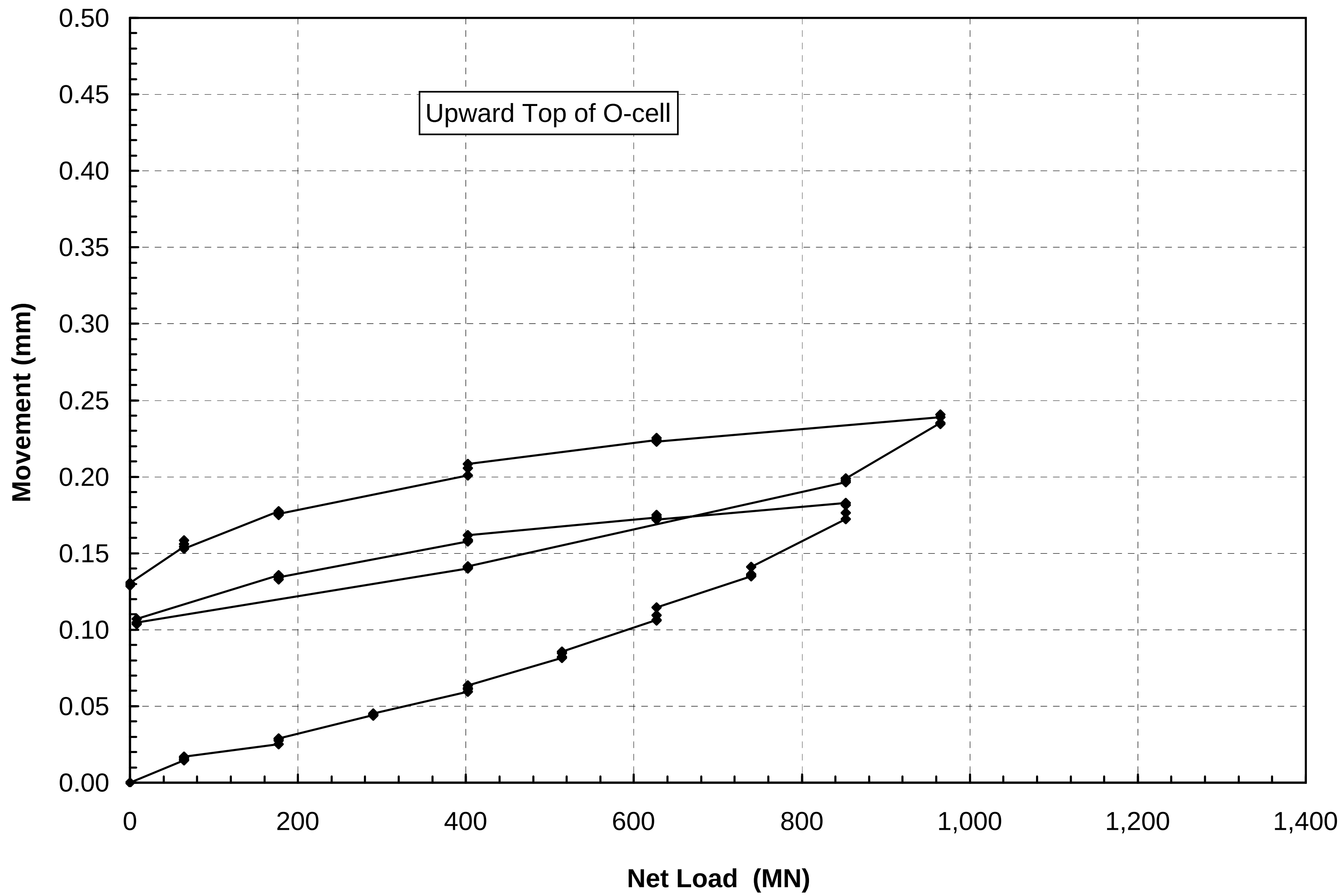

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Figure 1B of 8

Osterberg Cell Time vs. Displacement Plots

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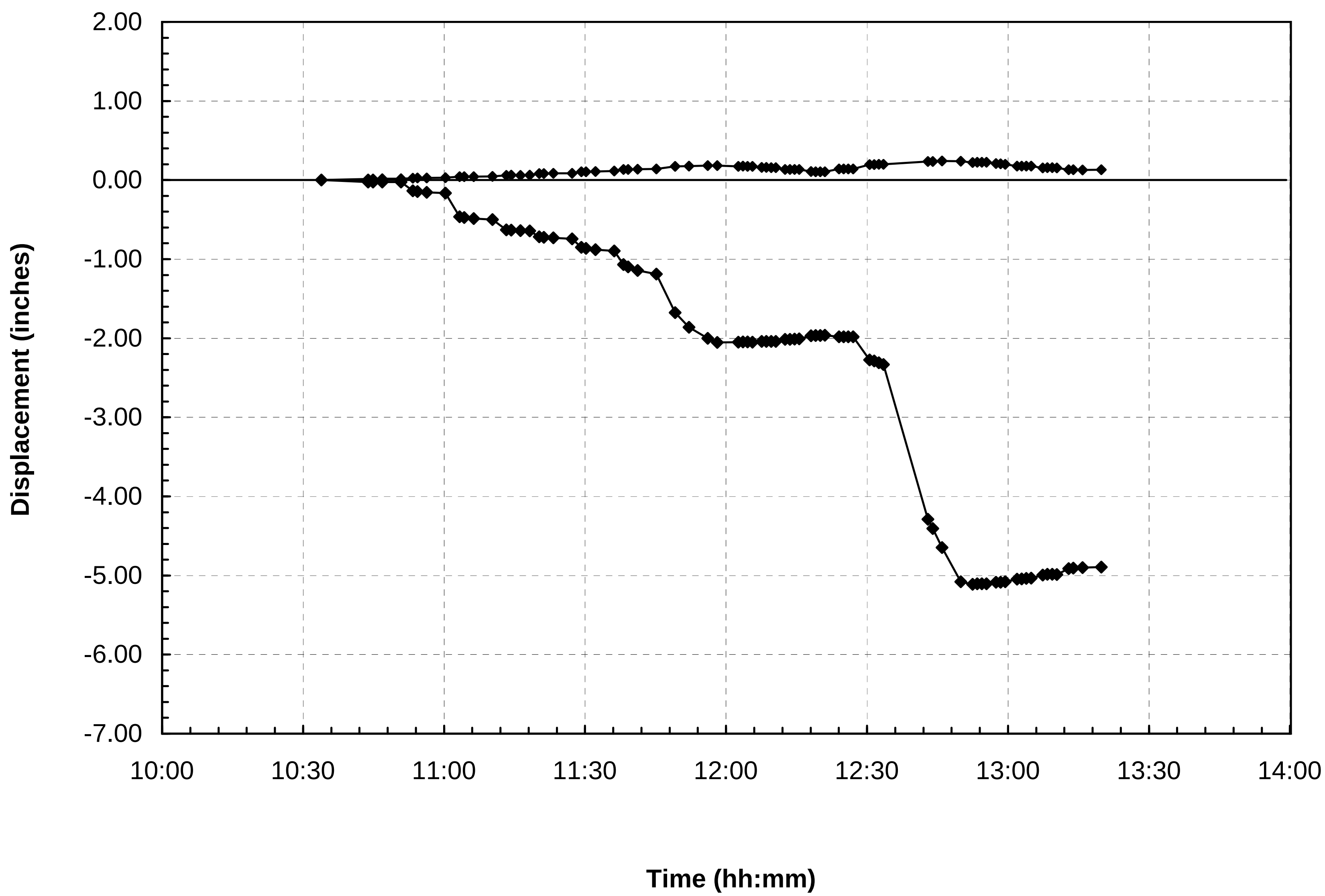

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Figure 2 of 8

Osterberg Cell Load vs. Time

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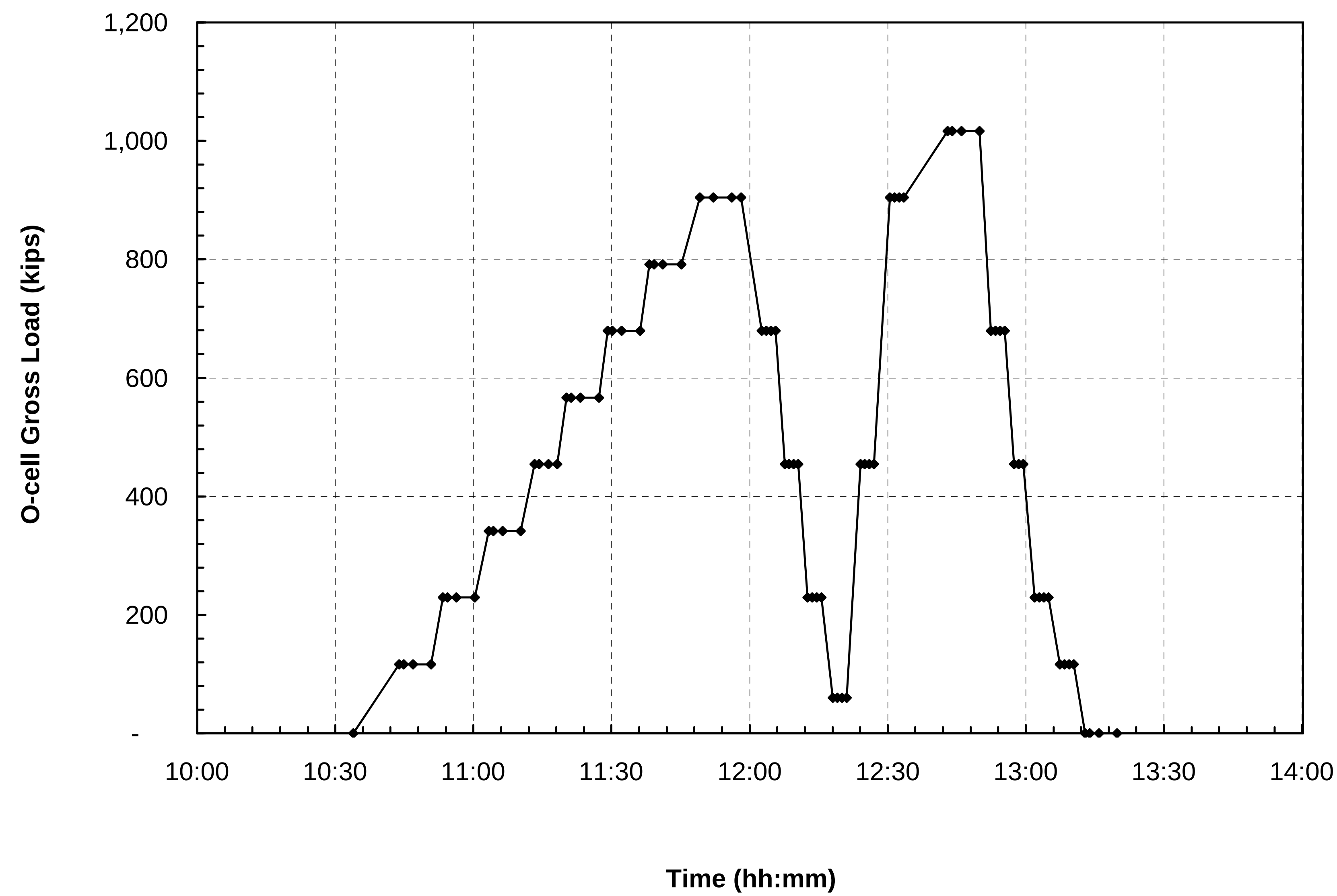

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Figure 3 of 8

Strain Gage Load Distribution Plots

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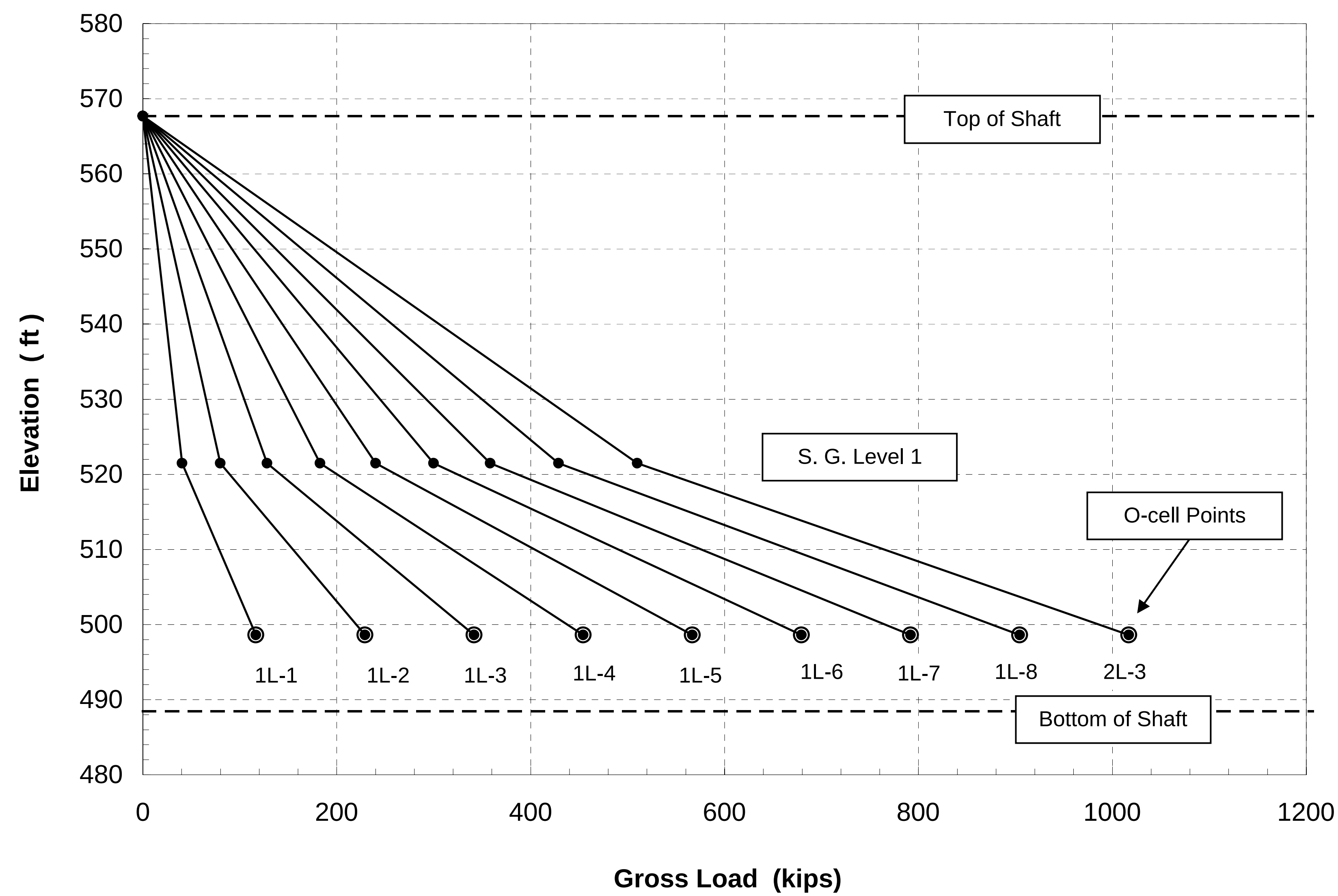

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Figure 4 of 8

Side Shear Creep Limit

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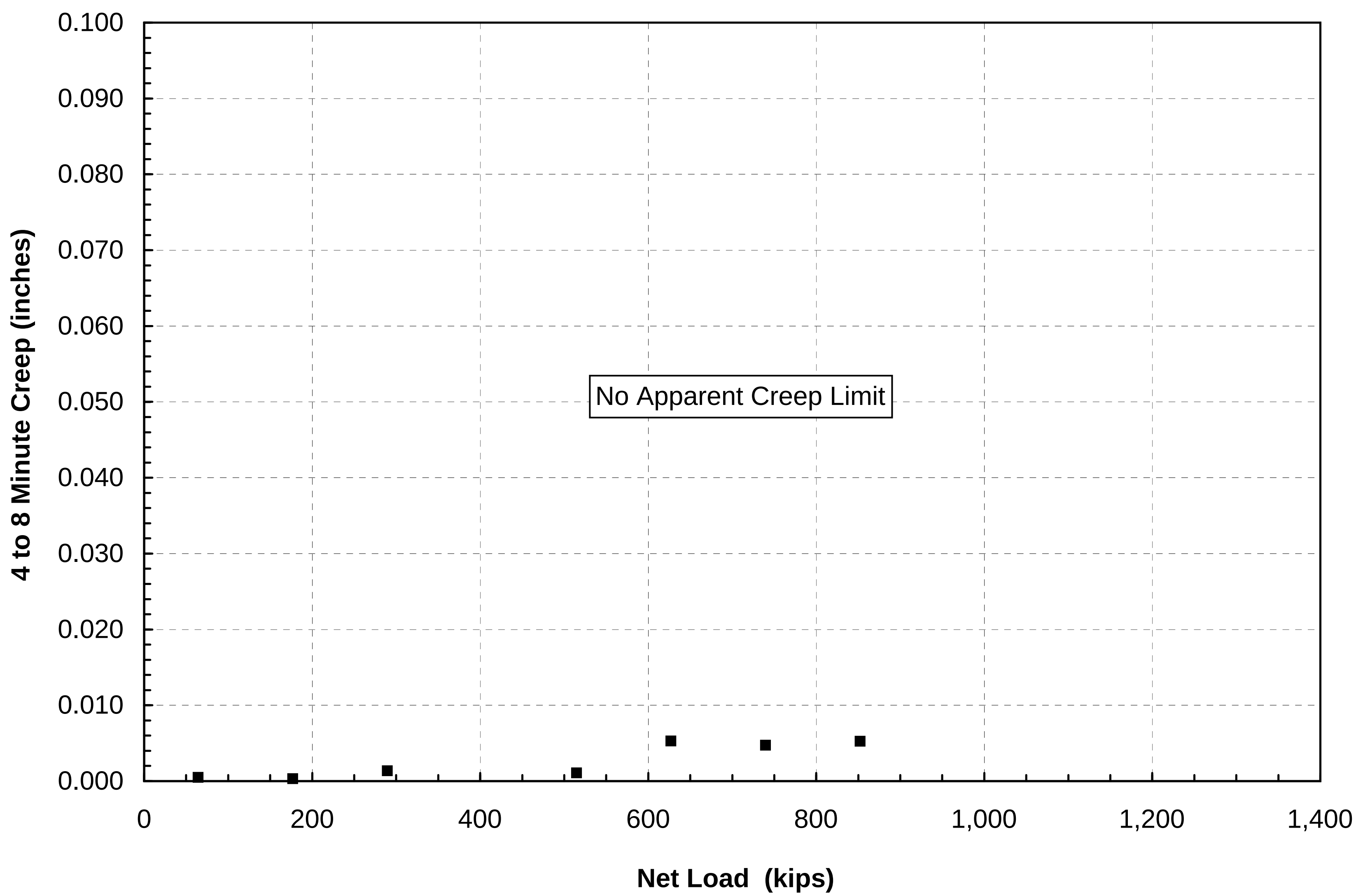

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Figure 5 of 8

Base Creep Limit

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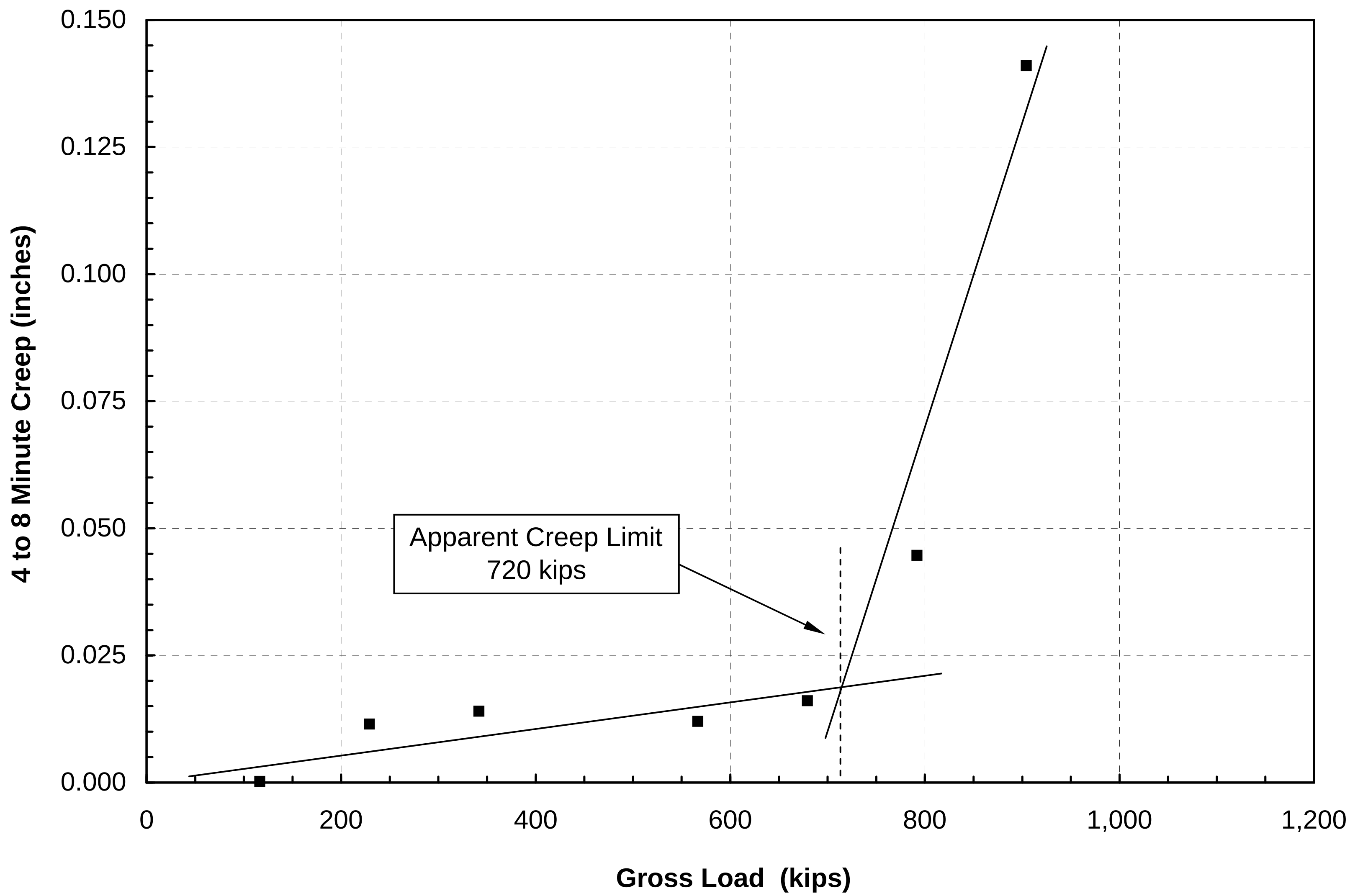

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Figure 6 of 8

Net Unit Shear vs. Upward Average Zone Movement

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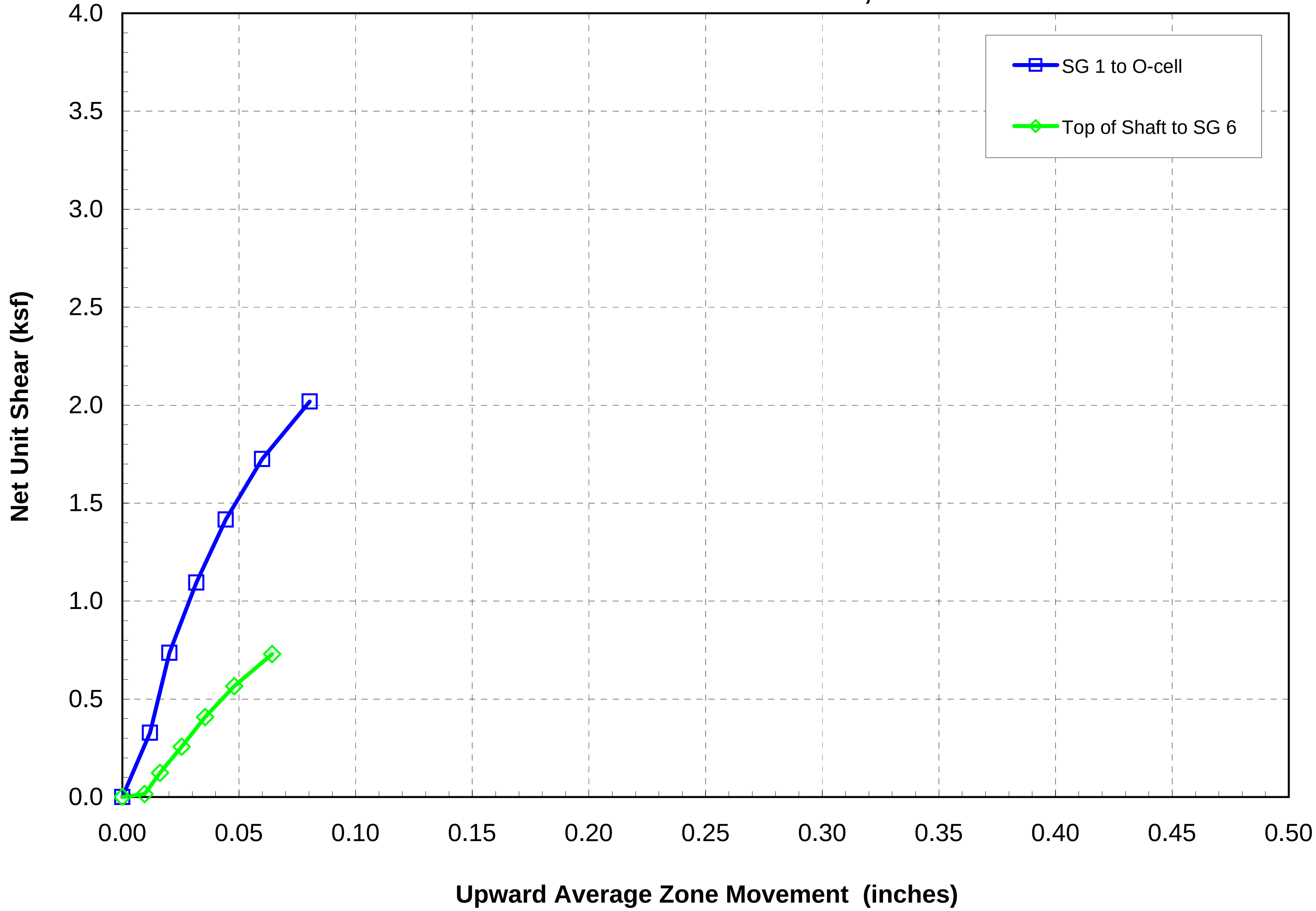

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Figure 7 of 8

Equivalent Top Load-Displacement Plots

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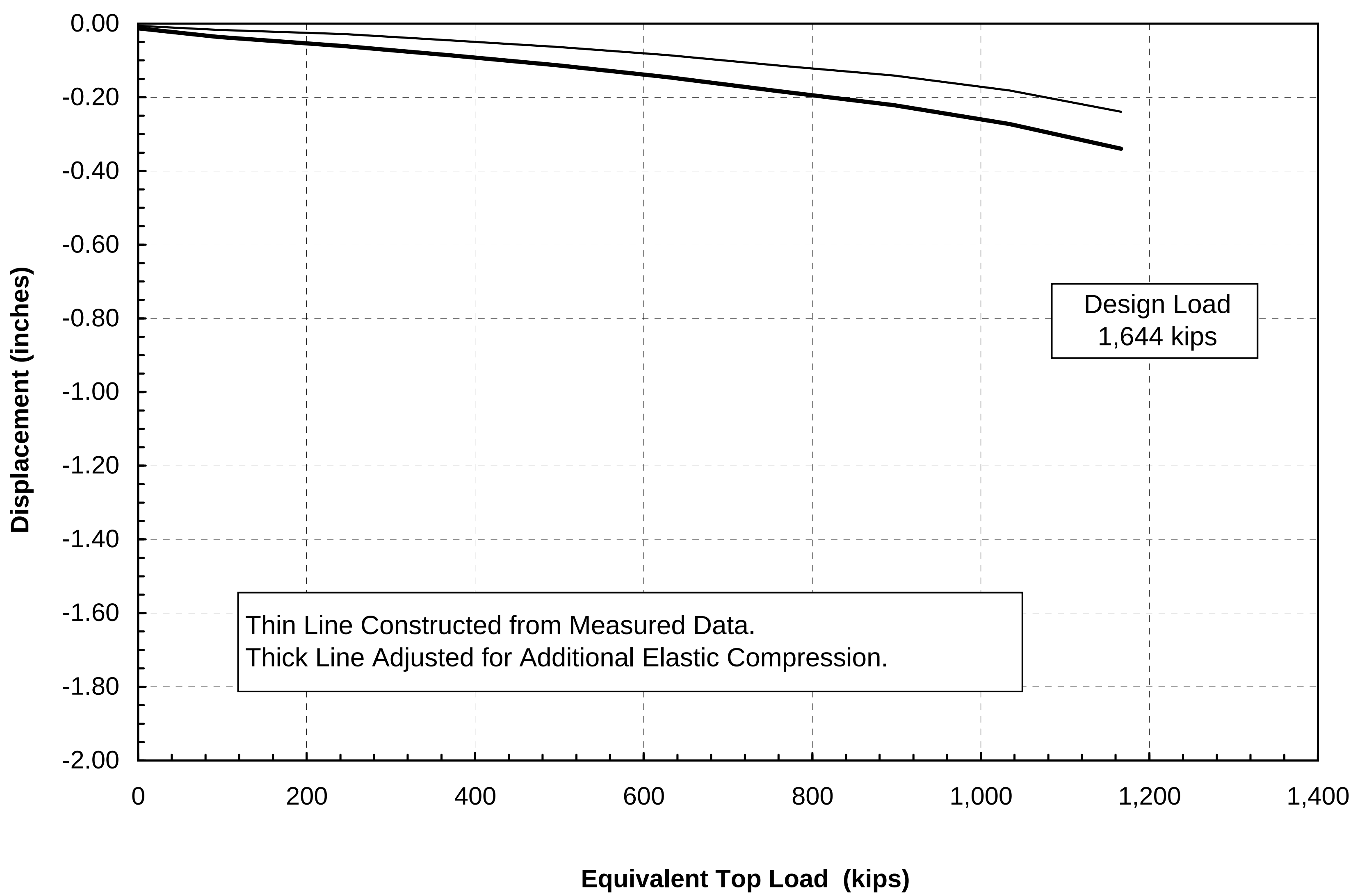

Loadtest Project No. 9981-2

Figure 8 of 8

Top of Shaft Movement and Compression
TexDOT - UT - ADSC Research - Austin, TX - TS 2

Load Test Increment	Time (h:m:s)	Time After Start Minutes	O-cell Pressure (psi)	Applied Load (kips)	TOS Indicator Readings Side A (inches)	TOS Indicator Readings Side B (inches)	TOS Indicator Readings Average (inches)	Telltale Compression Side A (inches)	Telltale Compression Side B (inches)	Telltale Compression Average (inches)
1L -0	10:34:00	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000
1L -1	10:44:00	1	500	117	0.003	0.004	0.003	0.011	0.011	0.011
1L -1	10:45:00	2	500	117	0.004	0.004	0.004	0.011	0.011	0.011
1L -1	10:47:00	4	500	117	0.005	0.004	0.005	0.012	0.012	0.012
1L -1	10:51:00	8	500	117	0.005	0.006	0.005	0.011	0.012	0.012
1L -2	10:53:30	1	1,000	229	0.006	0.005	0.005	0.019	0.021	0.020
1L -2	10:54:30	2	1,000	229	0.007	0.006	0.007	0.020	0.021	0.021
1L -2	10:56:30	4	1,000	229	0.007	0.007	0.007	0.021	0.022	0.022
1L -2	11:00:30	8	1,000	229	0.007	0.008	0.007	0.021	0.022	0.021
1L -3	11:03:30	1	1,500	342	0.014	0.011	0.013	0.032	0.032	0.032
1L -3	11:04:30	2	1,500	342	0.014	0.011	0.012	0.032	0.032	0.032
1L -3	11:06:30	4	1,500	342	0.012	0.011	0.011	0.033	0.033	0.033
1L -3	11:10:30	8	1,500	342	0.013	0.011	0.012	0.032	0.034	0.033
1L -4	11:13:30	1	2,000	454	0.015	0.014	0.015	0.043	0.046	0.045
1L -4	11:14:30	2	2,000	454	0.018	0.015	0.017	0.044	0.046	0.045
1L -4	11:16:30	4	2,000	454	0.017	0.014	0.016	0.044	0.047	0.045
1L -4	11:18:30	6	2,000	454	0.017	0.017	0.017	0.045	0.047	0.046
1L -5	11:20:30	1	2,500	567	0.024	0.022	0.023	0.057	0.059	0.058
1L -5	11:21:30	2	2,500	567	0.025	0.023	0.024	0.058	0.060	0.059
1L -5	11:23:30	4	2,500	567	0.028	0.023	0.025	0.058	0.060	0.059
1L -5	11:27:30	8	2,500	567	0.028	0.023	0.026	0.059	0.061	0.060
1L -6	11:29:30	1	3,000	679	0.034	0.032	0.033	0.072	0.074	0.073
1L -6	11:30:30	2	3,000	679	0.034	0.032	0.033	0.072	0.074	0.073
1L -6	11:32:30	4	3,000	679	0.038	0.033	0.035	0.073	0.075	0.074
1L -6	11:36:30	8	3,000	679	0.043	0.038	0.040	0.074	0.076	0.075
1L -7	11:38:30	1	3,500	792	0.049	0.047	0.048	0.086	0.088	0.087
1L -7	11:39:30	2	3,500	792	0.052	0.045	0.048	0.086	0.088	0.087
1L -7	11:41:30	4	3,500	792	0.048	0.049	0.048	0.087	0.089	0.088
1L -7	11:45:30	8	3,500	792	0.054	0.050	0.052	0.088	0.090	0.089
1L -8	11:49:30	1	4,000	904	0.072	0.065	0.069	0.103	0.104	0.103
1L -8	11:52:30	4	4,000	904	0.075	0.067	0.071	0.105	0.106	0.105
1L -8	11:56:30	8	4,000	904	0.077	0.073	0.075	0.106	0.107	0.107
1L -8	11:58:30	10	4,000	904	0.079	0.073	0.076	0.107	0.108	0.107
1U -1	12:03:00	1	3,000	679	0.080	0.072	0.076	0.096	0.097	0.096
1U -1	12:04:00	2	3,000	679	0.083	0.075	0.079	0.096	0.097	0.096
1U -1	12:05:00	3	3,000	679	0.082	0.073	0.078	0.095	0.097	0.096
1U -1	12:06:00	4	3,000	679	0.081	0.074	0.077	0.095	0.097	0.096
1U -2	12:08:00	1	2,000	454	0.081	0.072	0.076	0.084	0.086	0.085
1U -2	12:09:00	2	2,000	454	0.075	0.072	0.074	0.084	0.086	0.085
1U -2	12:10:00	3	2,000	454	0.074	0.072	0.073	0.084	0.086	0.085
1U -2	12:11:00	4	2,000	454	0.072	0.073	0.073	0.084	0.086	0.085
1U -3	12:13:00	1	1,000	229	0.073	0.065	0.069	0.065	0.066	0.066
1U -3	12:14:00	2	1,000	229	0.072	0.066	0.069	0.065	0.066	0.065
1U -3	12:15:00	3	1,000	229	0.070	0.066	0.068	0.064	0.066	0.065
1U -3	12:16:00	4	1,000	229	0.075	0.068	0.071	0.064	0.065	0.064
1U -4	12:18:30	1	250	60	0.064	0.060	0.062	0.044	0.046	0.045
1U -4	12:19:30	2	250	60	0.063	0.058	0.060	0.043	0.045	0.044
1U -4	12:20:30	3	250	60	0.061	0.058	0.059	0.043	0.045	0.044
1U -4	12:21:30	4	250	60	0.064	0.058	0.061	0.043	0.045	0.044

Top of Shaft Movement and Compression

TexDOT - UT - ADSC Research - Austin, TX - TS 2

Load Test Increment	Time (h:m:s)	Time After Start Minutes	O-cell Pressure (psi)	Applied Load (kips)	TOS Indicator Readings Side A (inches)	TOS Indicator Readings Side B (inches)	TOS Indicator Readings Average (inches)	Telltale Compression Side A (inches)	Telltale Compression Side B (inches)	Telltale Compression Average (inches)
2L -1	12:24:30	1	2,000	454	0.071	0.065	0.068	0.072	0.073	0.072
2L -1	12:25:30	2	2,000	454	0.071	0.065	0.068	0.072	0.073	0.073
2L -1	12:26:30	3	2,000	454	0.070	0.068	0.069	0.072	0.073	0.072
2L -1	12:27:30	4	2,000	454	0.070	0.068	0.069	0.072	0.073	0.072
2L -2	12:31:00	1	4,000	904	0.088	0.080	0.084	0.112	0.112	0.112
2L -2	12:32:00	2	4,000	904	0.090	0.081	0.086	0.112	0.112	0.112
2L -2	12:33:00	3	4,000	904	0.090	0.082	0.086	0.113	0.113	0.113
2L -2	12:34:00	4	4,000	904	0.090	0.082	0.086	0.113	0.113	0.113
2L -3	12:43:30	1	4,500	1,017	0.111	0.106	0.108	0.127	0.127	0.127
2L -3	12:44:30	2	4,500	1,017	0.110	0.105	0.108	0.127	0.126	0.127
2L -3	12:46:30	4	4,500	1,017	0.118	0.111	0.115	0.126	0.126	0.126
2L -3	12:50:30	8	4,500	1,017	0.115	0.108	0.112	0.128	0.127	0.127
2U -1	12:53:00	1	3,000	679	0.112	0.108	0.110	0.114	0.113	0.113
2U -1	12:54:00	2	3,000	679	0.114	0.111	0.113	0.113	0.113	0.113
2U -1	12:55:00	3	3,000	679	0.113	0.110	0.111	0.113	0.112	0.113
2U -1	12:56:00	4	3,000	679	0.112	0.110	0.111	0.113	0.112	0.113
2U -2	12:58:00	1	2,000	454	0.115	0.108	0.111	0.097	0.097	0.097
2U -2	12:59:00	2	2,000	454	0.113	0.105	0.109	0.097	0.096	0.097
2U -2	13:00:00	3	2,000	454	0.108	0.101	0.104	0.097	0.096	0.097
2U -3	13:02:30	1	1,000	229	0.101	0.098	0.099	0.076	0.076	0.076
2U -3	13:03:30	2	1,000	229	0.100	0.099	0.099	0.076	0.076	0.076
2U -3	13:04:30	3	1,000	229	0.102	0.100	0.101	0.075	0.075	0.075
2U -3	13:05:30	4	1,000	229	0.108	0.097	0.103	0.075	0.075	0.075
2U -4	13:08:00	1	500	117	0.098	0.089	0.094	0.059	0.060	0.059
2U -4	13:09:00	2	500	117	0.099	0.094	0.097	0.059	0.060	0.059
2U -4	13:10:00	3	500	117	0.102	0.097	0.099	0.059	0.060	0.059
2U -4	13:11:00	4	500	117	0.099	0.091	0.095	0.059	0.060	0.059
2U -5	13:13:30	1	0	0	0.088	0.083	0.086	0.044	0.045	0.045
2U -5	13:14:30	2	0	0	0.089	0.083	0.086	0.044	0.045	0.044
2U -5	13:16:30	4	0	0	0.088	0.081	0.084	0.044	0.045	0.044
2U -5	13:20:30	8	0	0	0.089	0.083	0.086	0.043	0.044	0.044

O-cell Expansion

TexDOT - UT - ADSC Research - Austin, TX - TS 2

Load Test Increment	Time (h:m:s)	Time After Start Minutes	O-cell Pressure (psi)	Applied Load (kips)	LVWDT Readings (Expansion) 12-18853 (inches)	12-18854 (inches)	12-18855 (inches)	12-18856 (inches)	Average (inches)
1L -0	10:34:00	0	0	0	0.000	0.000	0.000	0.000	0.000
1L -1	10:44:00	1	500	117	0.038	0.037	0.039	0.042	0.039
1L -1	10:45:00	2	500	117	0.039	0.037	0.040	0.042	0.039
1L -1	10:47:00	4	500	117	0.039	0.038	0.040	0.043	0.040
1L -1	10:51:00	8	500	117	0.040	0.038	0.041	0.043	0.041
1L -2	10:53:30	1	1,000	229	0.159	0.159	0.162	0.165	0.161
1L -2	10:54:30	2	1,000	229	0.170	0.169	0.172	0.175	0.172
1L -2	10:56:30	4	1,000	229	0.181	0.181	0.184	0.187	0.183
1L -2	11:00:30	8	1,000	229	0.193	0.192	0.196	0.198	0.195
1L -3	11:03:30	1	1,500	342	0.503	0.503	0.509	0.511	0.507
1L -3	11:04:30	2	1,500	342	0.514	0.514	0.520	0.522	0.518
1L -3	11:06:30	4	1,500	342	0.527	0.527	0.533	0.536	0.531
1L -3	11:10:30	8	1,500	342	0.543	0.543	0.548	0.551	0.546
1L -4	11:13:30	1	2,000	454	0.682	0.684	0.691	0.695	0.688
1L -4	11:14:30	2	2,000	454	0.689	0.690	0.697	0.701	0.694
1L -4	11:16:30	4	2,000	454	0.696	0.697	0.704	0.708	0.701
1L -4	11:18:30	6	2,000	454	0.701	0.701	0.708	0.712	0.705
1L -5	11:20:30	1	2,500	567	0.794	0.793	0.802	0.806	0.799
1L -5	11:21:30	2	2,500	567	0.802	0.801	0.809	0.814	0.806
1L -5	11:23:30	4	2,500	567	0.811	0.810	0.818	0.823	0.815
1L -5	11:27:30	8	2,500	567	0.824	0.823	0.831	0.836	0.828
1L -6	11:29:30	1	3,000	679	0.952	0.949	0.959	0.966	0.956
1L -6	11:30:30	2	3,000	679	0.965	0.963	0.973	0.980	0.970
1L -6	11:32:30	4	3,000	679	0.984	0.980	0.990	0.997	0.988
1L -6	11:36:30	8	3,000	679	1.005	1.002	1.011	1.019	1.009
1L -7	11:38:30	1	3,500	792	1.198	1.193	1.204	1.213	1.202
1L -7	11:39:30	2	3,500	792	1.230	1.224	1.236	1.245	1.234
1L -7	11:41:30	4	3,500	792	1.275	1.270	1.282	1.290	1.279
1L -7	11:45:30	8	3,500	792	1.324	1.320	1.331	1.340	1.329
1L -8	11:49:30	1	4,000	904	1.846	1.837	1.847	1.863	1.848
1L -8	11:52:30	4	4,000	904	2.033	2.027	2.034	2.051	2.036
1L -8	11:56:30	8	4,000	904	2.180	2.168	2.182	2.201	2.183
1L -8	11:58:30	10	4,000	904	2.232	2.221	2.234	2.253	2.235
1U -1	12:03:00	1	3,000	679	2.219	2.207	2.223	2.236	2.221
1U -1	12:04:00	2	3,000	679	2.220	2.207	2.222	2.237	2.221
1U -1	12:05:00	3	3,000	679	2.220	2.207	2.223	2.237	2.222
1U -1	12:06:00	4	3,000	679	2.220	2.207	2.223	2.237	2.222
1U -2	12:08:00	1	2,000	454	2.203	2.185	2.206	2.209	2.201
1U -2	12:09:00	2	2,000	454	2.202	2.184	2.206	2.208	2.200
1U -2	12:10:00	3	2,000	454	2.202	2.183	2.203	2.208	2.199
1U -2	12:11:00	4	2,000	454	2.202	2.183	2.203	2.207	2.199
1U -3	12:13:00	1	1,000	229	2.152	2.134	2.153	2.153	2.148
1U -3	12:14:00	2	1,000	229	2.150	2.133	2.152	2.152	2.147
1U -3	12:15:00	3	1,000	229	2.150	2.131	2.151	2.150	2.145
1U -3	12:16:00	4	1,000	229	2.149	2.130	2.150	2.148	2.144
1U -4	12:18:30	1	250	60	2.078	2.065	2.077	2.077	2.074
1U -4	12:19:30	2	250	60	2.075	2.062	2.075	2.073	2.071
1U -4	12:20:30	3	250	60	2.073	2.060	2.073	2.070	2.069
1U -4	12:21:30	4	250	60	2.071	2.058	2.071	2.068	2.067

O-cell Expansion

TexDOT - UT - ADSC Research - Austin, TX - TS 2

Load Test Increment	Time (h:m:s)	Time After Start Minutes	O-cell Pressure (psi)	Applied Load (kips)	LVWDT Readings (Expansion) 12-18853 (inches)	12-18854 (inches)	12-18855 (inches)	12-18856 (inches)	Average (inches)
2L -1	12:24:30	1	2,000	454	2.120	2.115	2.123	2.134	2.123
2L -1	12:25:30	2	2,000	454	2.120	2.114	2.124	2.135	2.123
2L -1	12:26:30	3	2,000	454	2.120	2.114	2.124	2.135	2.123
2L -1	12:27:30	4	2,000	454	2.121	2.114	2.124	2.135	2.124
2L -2	12:31:00	1	4,000	904	2.464	2.453	2.472	2.487	2.469
2L -2	12:32:00	2	4,000	904	2.481	2.470	2.488	2.503	2.486
2L -2	12:33:00	3	4,000	904	2.505	2.493	2.513	2.528	2.510
2L -2	12:34:00	4	4,000	904	2.526	2.514	2.532	2.548	2.530
2L -3	12:43:30	1	4,500	1,017	4.527	4.500	4.533	4.538	4.525
2L -3	12:44:30	2	4,500	1,017	4.640	4.619	4.650	4.658	4.642
2L -3	12:46:30	4	4,500	1,017	4.888	4.864	4.894	4.897	4.886
2L -3	12:50:30	8	4,500	1,017	5.319	5.291	5.331	5.336	5.319
2U -1	12:53:00	1	3,000	679	5.346	5.312	5.350	5.335	5.336
2U -1	12:54:00	2	3,000	679	5.344	5.310	5.340	5.334	5.332
2U -1	12:55:00	3	3,000	679	5.344	5.310	5.333	5.334	5.330
2U -1	12:56:00	4	3,000	679	5.343	5.310	5.335	5.334	5.331
2U -2	12:58:00	1	2,000	454	5.305	5.273	5.306	5.289	5.293
2U -2	12:59:00	2	2,000	454	5.303	5.270	5.303	5.286	5.290
2U -2	13:00:00	3	2,000	454	5.289	5.264	5.286	5.282	5.280
2U -3	13:02:30	1	1,000	229	5.233	5.208	5.235	5.218	5.224
2U -3	13:03:30	2	1,000	229	5.226	5.202	5.227	5.215	5.218
2U -3	13:04:30	3	1,000	229	5.223	5.199	5.217	5.212	5.213
2U -3	13:05:30	4	1,000	229	5.221	5.197	5.216	5.211	5.211
2U -4	13:08:00	1	500	117	5.156	5.133	5.156	5.144	5.147
2U -4	13:09:00	2	500	117	5.150	5.132	5.146	5.142	5.142
2U -4	13:10:00	3	500	117	5.151	5.130	5.146	5.141	5.142
2U -4	13:11:00	4	500	117	5.150	5.129	5.145	5.140	5.141
2U -5	13:13:30	1	0	0	5.054	5.031	5.048	5.039	5.043
2U -5	13:14:30	2	0	0	5.047	5.024	5.042	5.034	5.037
2U -5	13:16:30	4	0	0	5.039	5.018	5.035	5.025	5.029
2U -5	13:20:30	8	0	0	5.031	5.011	5.030	5.021	5.023

Upward and Downward Movement and Creep
TexDOT - UT - ADSC Research - Austin, TX - TS 2

Load Test Increment	Time 0 (h:m:s)	Time After Start Minutes	O-cell Pressure (psi)	Applied Load (kips)	Net Load kips (kips)	Top O-cell Movement (inches)	Upward Creep (inches)	Bottom O-cell Movement (inches)	Downward Creep (inches)
1L -0	10:34:00	0	0	0	0	0.000		0.000	
1L -1	10:44:00	1	500	117	64	0.015		-0.024	
1L -1	10:45:00	2	500	117	64	0.015		-0.024	
1L -1	10:47:00	4	500	117	64	0.016		-0.024	
1L -1	10:51:00	8	500	117	64	0.017	0.000	-0.024	0.000
1L -2	10:53:30	1	1,000	229	177	0.025		-0.136	
1L -2	10:54:30	2	1,000	229	177	0.027		-0.144	
1L -2	10:56:30	4	1,000	229	177	0.029		-0.154	
1L -2	11:00:30	8	1,000	229	177	0.029	0.000	-0.166	0.011
1L -3	11:03:30	1	1,500	342	290	0.044		-0.462	
1L -3	11:04:30	2	1,500	342	290	0.044		-0.473	
1L -3	11:06:30	4	1,500	342	290	0.044		-0.487	
1L -3	11:10:30	8	1,500	342	290	0.045	0.001	-0.501	0.014
1L -4	11:13:30	1	2,000	454	402	0.059		-0.629	
1L -4	11:14:30	2	2,000	454	402	0.062		-0.632	
1L -4	11:16:30	4	2,000	454	402	0.061		-0.640	
1L -4	11:18:30	6	2,000	454	402	0.063		-0.642	
1L -5	11:20:30	1	2,500	567	515	0.082		-0.717	
1L -5	11:21:30	2	2,500	567	515	0.082		-0.724	
1L -5	11:23:30	4	2,500	567	515	0.085		-0.731	
1L -5	11:27:30	8	2,500	567	515	0.086	0.001	-0.743	0.012
1L -6	11:29:30	1	3,000	679	627	0.106		-0.850	
1L -6	11:30:30	2	3,000	679	627	0.106		-0.864	
1L -6	11:32:30	4	3,000	679	627	0.109		-0.878	
1L -6	11:36:30	8	3,000	679	627	0.115	0.005	-0.894	0.016
1L -7	11:38:30	1	3,500	792	740	0.135		-1.067	
1L -7	11:39:30	2	3,500	792	740	0.135		-1.098	
1L -7	11:41:30	4	3,500	792	740	0.136		-1.143	
1L -7	11:45:30	8	3,500	792	740	0.141	0.005	-1.188	0.045
1L -8	11:49:30	1	4,000	904	852	0.172		-1.676	
1L -8	11:52:30	4	4,000	904	852	0.176		-1.860	
1L -8	11:56:30	8	4,000	904	852	0.182	0.005	-2.001	0.141
1L -8	11:58:30	10	4,000	904	852	0.183		-2.052	
1U -1	12:03:00	1	3,000	679	627	0.172		-2.049	
1U -1	12:04:00	2	3,000	679	627	0.175		-2.046	
1U -1	12:05:00	3	3,000	679	627	0.174		-2.048	
1U -1	12:06:00	4	3,000	679	627	0.173		-2.048	
1U -2	12:08:00	1	2,000	454	402	0.162		-2.039	
1U -2	12:09:00	2	2,000	454	402	0.159		-2.041	
1U -2	12:10:00	3	2,000	454	402	0.158		-2.041	
1U -2	12:11:00	4	2,000	454	402	0.158		-2.041	
1U -3	12:13:00	1	1,000	229	177	0.134		-2.014	
1U -3	12:14:00	2	1,000	229	177	0.134		-2.012	
1U -3	12:15:00	3	1,000	229	177	0.133		-2.012	
1U -3	12:16:00	4	1,000	229	177	0.136		-2.009	
1U -4	12:18:30	1	250	60	8	0.107		-1.967	
1U -4	12:19:30	2	250	60	8	0.105		-1.967	
1U -4	12:20:30	3	250	60	8	0.104		-1.966	
1U -4	12:21:30	4	250	60	8	0.105		-1.962	

Upward and Downward Movement and Creep

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Load Test Increment	Time 0 (h:m:s)	Time After Start Minutes	O-cell Pressure (psi)	Applied Load (kips)	Net Load kips (kips)	Top O-cell Movement (inches)	Upward Creep (inches)	Bottom O-cell Movement (inches)	Downward Creep (inches)
2L -1	12:24:30	1	2,000	454	402	0.140		-1.983	
2L -1	12:25:30	2	2,000	454	402	0.141		-1.983	
2L -1	12:26:30	3	2,000	454	402	0.141		-1.982	
2L -1	12:27:30	4	2,000	454	402	0.141		-1.982	
2L -2	12:31:00	1	4,000	904	852	0.196		-2.273	
2L -2	12:32:00	2	4,000	904	852	0.198		-2.288	
2L -2	12:33:00	3	4,000	904	852	0.199		-2.311	
2L -2	12:34:00	4	4,000	904	852	0.199		-2.332	
2L -3	12:43:30	1	4,500	1,017	965	0.235		-4.289	
2L -3	12:44:30	2	4,500	1,017	965	0.234		-4.407	
2L -3	12:46:30	4	4,500	1,017	965	0.241		-4.645	
2L -3	12:50:30	8	4,500	1,017	965	0.239	-0.002	-5.080	0.435
2U -1	12:53:00	1	3,000	679	627	0.223		-5.113	
2U -1	12:54:00	2	3,000	679	627	0.226		-5.106	
2U -1	12:55:00	3	3,000	679	627	0.224		-5.106	
2U -1	12:56:00	4	3,000	679	627	0.224		-5.107	
2U -2	12:58:00	1	2,000	454	402	0.208		-5.085	
2U -2	12:59:00	2	2,000	454	402	0.205		-5.085	
2U -2	13:00:00	3	2,000	454	402	0.201		-5.079	
2U -3	13:02:30	1	1,000	229	177	0.176		-5.048	
2U -3	13:03:30	2	1,000	229	177	0.175		-5.042	
2U -3	13:04:30	3	1,000	229	177	0.176		-5.037	
2U -3	13:05:30	4	1,000	229	177	0.177		-5.034	
2U -4	13:08:00	1	500	117	64	0.153		-4.994	
2U -4	13:09:00	2	500	117	64	0.156		-4.986	
2U -4	13:10:00	3	500	117	64	0.158		-4.984	
2U -4	13:11:00	4	500	117	64	0.154		-4.987	
2U -5	13:13:30	1	0	0	0	0.130		-4.912	
2U -5	13:14:30	2	0	0	0	0.130		-4.906	
2U -5	13:16:30	4	0	0	0	0.129		-4.901	
2U -5	13:20:30	8	0	0	0	0.129		-4.894	

Strain Gage Readings and Loads at Level 1

TexDOT - UT - ADSC Research - Austin, TX - TS 2

Load Test Increment	Time (h:m:s)	Time After Start Minutes	O-cell Pressure (psi)	Applied Load (kips)	Level 1 12-20187 $\mu\varepsilon$	Level 1 12-20188 $\mu\varepsilon$	Level 1 Av. Strain $\mu\varepsilon$	Level 1 Av. Load (kips)
1L -0	10:34:00	0	0	0	0	0	0	0
1L -1	10:44:00	1	500	117	16	15	16	40
1L -1	10:45:00	2	500	117	16	15	16	40
1L -1	10:47:00	4	500	117	16	16	16	40
1L -1	10:51:00	8	500	117	16	16	16	40
1L -2	10:53:30	1	1,000	229	30	30	30	77
1L -2	10:54:30	2	1,000	229	31	30	30	78
1L -2	10:56:30	4	1,000	229	31	31	31	79
1L -2	11:00:30	8	1,000	229	31	31	31	80
1L -3	11:03:30	1	1,500	342	48	48	48	123
1L -3	11:04:30	2	1,500	342	49	49	49	124
1L -3	11:06:30	4	1,500	342	49	49	49	126
1L -3	11:10:30	8	1,500	342	50	50	50	128
1L -4	11:13:30	1	2,000	454	69	70	69	178
1L -4	11:14:30	2	2,000	454	70	71	70	180
1L -4	11:16:30	4	2,000	454	70	72	71	182
1L -4	11:18:30	6	2,000	454	71	72	71	183
1L -5	11:20:30	1	2,500	567	90	93	92	235
1L -5	11:21:30	2	2,500	567	91	94	92	237
1L -5	11:23:30	4	2,500	567	91	94	93	238
1L -5	11:27:30	8	2,500	567	92	95	94	240
1L -6	11:29:30	1	3,000	679	113	117	115	294
1L -6	11:30:30	2	3,000	679	114	118	116	296
1L -6	11:32:30	4	3,000	679	114	118	116	298
1L -6	11:36:30	8	3,000	679	115	119	117	300
1L -7	11:38:30	1	3,500	792	134	140	137	351
1L -7	11:39:30	2	3,500	792	135	140	138	352
1L -7	11:41:30	4	3,500	792	136	142	139	356
1L -7	11:45:30	8	3,500	792	137	143	140	358
1L -8	11:49:30	1	4,000	904	160	166	163	418
1L -8	11:52:30	4	4,000	904	162	169	165	423
1L -8	11:56:30	8	4,000	904	163	170	167	427
1L -8	11:58:30	10	4,000	904	164	171	167	429
1U -1	12:03:00	1	3,000	679	151	158	154	395
1U -1	12:04:00	2	3,000	679	151	158	154	395
1U -1	12:05:00	3	3,000	679	151	158	154	395
1U -1	12:06:00	4	3,000	679	151	157	154	395
1U -2	12:08:00	1	2,000	454	137	144	140	359
1U -2	12:09:00	2	2,000	454	136	143	140	358
1U -2	12:10:00	3	2,000	454	136	143	140	358
1U -2	12:11:00	4	2,000	454	136	143	139	357
1U -3	12:13:00	1	1,000	229	104	110	107	275
1U -3	12:14:00	2	1,000	229	104	110	107	274
1U -3	12:15:00	3	1,000	229	103	109	106	271
1U -3	12:16:00	4	1,000	229	102	108	105	269
1U -4	12:18:30	1	250	60	67	72	69	178
1U -4	12:19:30	2	250	60	66	71	68	175
1U -4	12:20:30	3	250	60	65	71	68	174
1U -4	12:21:30	4	250	60	64	70	67	171

Strain Gage Readings and Loads at Level 1

TexDOT - UT - ADSC Research - Austin, TX - TS 2

Load Test Increment	Time (h:m:s)	Time After Start Minutes	O-cell Pressure (psi)	Applied Load (kips)	Level 1			
					12-20187 με	12-20188 με	Av. Strain με	Av. Load (kips)
2L -1	12:24:30	1	2,000	454	109	115	112	288
2L -1	12:25:30	2	2,000	454	109	116	112	288
2L -1	12:26:30	3	2,000	454	109	116	112	288
2L -1	12:27:30	4	2,000	454	109	116	113	288
2L -2	12:31:00	1	4,000	904	172	179	176	450
2L -2	12:32:00	2	4,000	904	172	179	175	449
2L -2	12:33:00	3	4,000	904	172	180	176	451
2L -2	12:34:00	4	4,000	904	173	180	176	451
2L -3	12:43:30	1	4,500	1,017	193	201	197	505
2L -3	12:44:30	2	4,500	1,017	193	201	197	504
2L -3	12:46:30	4	4,500	1,017	194	201	197	506
2L -3	12:50:30	8	4,500	1,017	195	203	199	510
2U -1	12:53:00	1	3,000	679	178	185	182	465
2U -1	12:54:00	2	3,000	679	178	185	181	464
2U -1	12:55:00	3	3,000	679	177	185	181	464
2U -1	12:56:00	4	3,000	679	177	184	181	463
2U -2	12:58:00	1	2,000	454	156	162	159	406
2U -2	12:59:00	2	2,000	454	154	160	157	403
2U -2	13:00:00	3	2,000	454	154	160	157	403
2U -3	13:02:30	1	1,000	229	119	123	121	310
2U -3	13:03:30	2	1,000	229	118	122	120	307
2U -3	13:04:30	3	1,000	229	117	121	119	305
2U -3	13:05:30	4	1,000	229	116	121	119	304
2U -4	13:08:00	1	500	117	88	92	90	230
2U -4	13:09:00	2	500	117	89	92	91	232
2U -4	13:10:00	3	500	117	89	93	91	233
2U -4	13:11:00	4	500	117	89	93	91	233
2U -5	13:13:30	1	0	0	61	63	62	159
2U -5	13:14:30	2	0	0	60	63	61	157
2U -5	13:16:30	4	0	0	60	62	61	157
2U -5	13:20:30	8	0	0	59	65	62	159

Load	Time	Time After	O-cell	Applied	Level 1		Level 2		Level 3		Level 4				Level 5				Level 6				Level 7	
Test		Start	Pressure	Load	112	Av. Load	111	Av. Load	114	Av. Load	203	206	Av. Strain	Av. Load	204	209	Av. Strain	Av. Load	207	201	Av. Strain	Av. Load	205	Av. Load
Increment	(h:m:s)	Minutes	(psi)	(kips)	με	(kips)	με	(kips)	με	(kips)	με	με	με	(kips)	με	με	με	(kips)	με	με	με	(kips)	με	(kips)
1L -0	10:34:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1L -1	10:44:00	1	500	117	-22	51	-37	87	-42	98	-43	-42	-43	100	-25	-30	-28	65	-15	-16	-15	36	-5	11
1L -1	10:45:00	2	500	117	-22	51	-38	89	-43	100	-44	-42	-43	100	-25	-30	-28	65	-15	-16	-15	36	-4	9
1L -1	10:47:00	4	500	117	-23	53	-38	90	-43	101	-44	-43	-44	102	-26	-30	-28	66	-16	-16	-16	37	-5	11
1L -1	10:51:00	8	500	117	-23	53	-39	91	-44	102	-45	-43	-44	103	-27	-31	-29	68	-16	-17	-16	38	-5	11
1L -2	10:53:30	1	1,000	229	-41	95	-66	155	-73	171	-75	-72	-74	172	-45	-44	-44	104	-25	-17	-21	49	-9	20
1L -2	10:54:30	2	1,000	229	-42	98	-67	157	-74	172	-75	**-73**	-74	173	-46	-43	-44	104	-25	-16	-21	49	-9	20
1L -2	10:56:30	4	1,000	229	-43	100	-68	159	-75	174	-76	-73	-74	174	-45	-44	-45	104	-26	-17	-22	51	-9	21
1L -2	11:00:30	8	1,000	229	-43	101	-69	160	-75	174	-76	-72	-74	173	-44	-44	-44	103	-28	-17	-23	53	-9	21
1L -3	11:03:30	1	1,500	342	-64	149	-97	227	-105	244	-108	-100	-104	244	-70	-54	-62	145	-45	-18	-32	74	-25	59
1L -3	11:04:30	2	1,500	342	-65	151	-97	228	-105	246	-109	-101	-105	245	-76	-55	-66	154	-46	-20	-33	77	-26	61
1L -3	11:06:30	4	1,500	342	-65	153	-98	230	-106	248	-110	-102	-106	248	-76	-57	-66	155	-47	-22	-35	81	-28	65
1L -3	11:10:30	8	1,500	342	-67	156	-99	232	-107	250	-112	-102	-107	250	-81	-58	-70	163	-49	-24	-36	85	-29	67
1L -4	11:13:30	1	2,000	454	-91	212	-130	304	-140	326	-149	-141	-145	339	-96	-92	-94	220	-84	-51	-67	158	-63	147
1L -4	11:14:30	2	2,000	454	-92	215	-131	307	-140	327	-150	-142	-146	341	-97	-93	-95	221	-85	-53	-69	160	-64	151
1L -4	11:16:30	4	2,000	454	-92	216	-132	308	-141	329	-151	-143	-147	344	-98	-94	-96	224	-87	-54	-70	165	-65	152
1L -4	11:18:30	6	2,000	454	-93	217	-132	309	-141	329	-151	-143	-147	343	-97	-94	-96	224	-87	-55	-71	166	-65	152
1L -5	11:20:30	1	2,500	567	-117	274	-162	380	-172	402	-188	-183	-185	433	-129	-131	-130	304	-123	-84	-104	242	-100	233
1L -5	11:21:30	2	2,500	567	-118	277	-163	381	-172	403	-189	-183	-186	435	-128	-132	-130	304	-124	-85	-105	245	-101	235
1L -5	11:23:30	4	2,500	567	-119	278	-163	382	-172	403	-189	-183	-186	435	-128	-132	-130	303	-124	-85	-104	244	-101	235
1L -5	11:27:30	8	2,500	567	-120	281	-165	387	-174	407	-191	-185	-188	439	-130	-134	-132	308	-127	-87	-107	250	-102	239
1L -6	11:29:30	1	3,000	679	-146	341	-197	460	-205	480	-229	-226	-227	531	-159	-169	-164	384	-162	-115	-138	323	-138	323
1L -6	11:30:30	2	3,000	679	-146	342	-197	461	-206	481	-229	-226	-228	532	-160	-169	-165	385	-163	-115	-139	324	-139	325
1L -6	11:32:30	4	3,000	679	-147	344	-198	463	-207	484	-230	-227	-229	534	-177	-170	-173	405	-163	-115	-139	325	-139	326
1L -6	11:36:30	8	3,000	679	-148	347	-199	466	-207	485	-232	-228	-230	537	-162	-170	-166	388	-163	-116	-140	326	-139	326
1L -7	11:38:30	1	3,500	792	-171	401	-228	534	-237	554	-267	-264	-265	621	-185	-200	-193	450	-195	-139	-167	391	-173	404
1L -7	11:39:30	2	3,500	792	-172	402	-228	534	-237	554	-266	-264	-265	619	-184	-199	-192	448	-194	-138	-166	389	-173	404
1L -7	11:41:30	4	3,500	792	-174	407	-231	541	-239	560	-269	-266	-267	625	-186	-201	-193	452	-196	-139	-168	392	-174	407
1L -7	11:45:30	8	3,500	792	-175	410	-232	543	-240	561	-270	-267	-269	628	-185	-201	-193	452	-196	-139	-167	391	-174	406
1L -8	11:49:30	1	4,000	904	-202	472	-266	621	-272	637	-305	-307	-306	716	-211	-231	-221	517	-227	-155	-191	447	-210	491
1L -8	11:52:30	4	4,000	904	-205	479	-269	630	-275	644	-308	-311	-310	724	-211	-234	-223	521	-226	-155	-191	446	-211	493
1L -8	11:56:30	8	4,000	904	-206	482	-271	633	-277	647	-309	-314	-312	729	-210	-238	-224	524	-224	-155	-190	443	-210	491
1L -8	11:58:30	10	4,000	904	-207	484	-272	635	-278	650	-310	-316	-313	731	-210	-239	-224	525	-224	-155	-190	443	-210	491
1U -1	12:03:00	1	3,000	679	-188	440	-241	563	-234	548	-243	-241	-242	565	-186	-190	-188	439	-192	-126	-159	372	-189	441
1U -1	12:04:00	2	3,000	679	-189	441	-241	564	-235	550	-245	-243	-244	571	-187	-192	-189	442	-192	-127	-160	373	-188	440
1U -1	12:05:00	3	3,000	679	-189	441	-241	564	-235	550	-245	-243	-244	570	-186	-190	-188	440	-191	-127	-159	372	-187	436
1U -1	12:06:00	4	3,000	679	-189	441	-241	564	-235	550	-245	-244	-245	572	-187	-191	-189	442	-190	-127	-159	371	-186	434
1U -2	12:08:00	1	2,000	454	-170	397	-211	492	-194	454	-189	-180	-184	431	-145	-150	-148	346	-166	-104	-135	316	-174	406
1U -2	12:09:00	2	2,000	454	-169	396	-210	491	-193	452	-187	-178	-183	427	-144	-149	-147	343	-166	-103	-134	314	-173	403
1U -2	12:10:00	3	2,000	454	-169	396	-209	489	-192	449	-186	-177	-182	424	-153	-148	-151	352	-165	-103	-134	313	-172	401
1U -2	12:11:00	4	2,000	454	-169	395	-209	488	-194	453	-189	-185	-187	437	-158	-149	-153	359	-162	-104	-133	311	-174	407
1U -3	12:13:00	1	1,000	229	-127	297	-147	344	-130	305	-120	-107	-114	266	-113	-93	-103	242	-128	-70	-99	232	-151	354
1U -3	12:14:00	2	1,000	229	-127	297	-148	345	-131	306	-121	-108	-115	268	-118	-94	-106	247	-128	-71	-99	232	-151	354
1U -3	12:15:00	3	1,000	229	-126	294	-146	341	-129	302	-119	-105	-112	263	-118	-92	-105	245	-127	-70	-98	230	-150	351
1U -3	12:16:00	4	1,000	229	-124	291	-144	337	-127	298	-117	-103	-110	257	-121	-91	-106	247	-126	-69	-98	228	-149	348
1U -4	12:18:30	1	250	60	-81	189	-89	208	-76	178	-66	-42	-54	126	-78	-41	-59	139	-91	-38	-64	151	-121	283
1U -4	12:19:30	2	250	60	-80	188	-87	205	-75	176	-64	-40	-52	121	-89	-40	-64	150	-91	-37	-64	150	-119	279
1U -4	12:20:30	3	250	60	-79	185	-86	201	-74	172	-63	-38	-50	117	-75	-38	-57	133	-89	-36	-63	147	-118	277
1U -4	12:21:30	4	250	60	-78	182	-84	197	-72	169	-61	-36	-49	114	-75	-37	-56	131	-88	-36	-62	145	-117	274
2L -1	12:24:30	1	2,000	454	-137	320	-173	404	-166	388	-168	-156	-162	378	-147	-119	-133	311	-136	-83	-110	257	-142	332
2L -1	12:25:30	2	2,000	454	-137	320	-172	403	-165	387	-167	-155	-161	377	-146	-119	-133	310	-136	-83	-110	257	-142	331
2L -1	12:26:30	3	2,000	454	-137	320	-173	404	-165	387	-168	-156	-162	379	-145	-119	-132	310	-136	-84	-110	257	-141	330
2L -1	12:27:30	4	2,000	454	-137	320	-172	403	-165	387	-168	-156	-162	379	-143	-119	-131	307	-136	-84	-110	257	-141	329
2L -2	12:31:00	1	4,000	904	-216	505	-278	649	-280	656	-306	-316	-311	727	-213	-245	-229	536	-222	-163	-192	450	-213	497
2L -2	12:32:00	2	4,000	904	-216	504	-277	648	-279	653	-306	-315	-311	726	-212	-245	-228	534	-220	-162	-191	447	-212	495
2L -2	12:33:00	3	4,000	904	-216	505	-278	650	-280	656	-307	-317	-312	729	-213	-246	-229	537	-221	-163	-192	448	-212	496
2L -2	12:34:00	4	4,000	904	-217	507	-279	651	-281	658	-307	-318	-313	731	-213	-247	-230	538	-221	-163	-192	449	-212	496
2L -3	12:43:30	1	4,500	1,017	-241	562	-311	726	-313	732	-334	-369	-352	822	-224	-308	-266	622	-244	-204	-224	524	-255	597
2L -3	12:44:30	2	4,500	1,017	-240	561	-310	724	-312	729	-331	-368	-350	818	-223	-307	-265	619	-243	-204	-224	523	-253	592
2L -3	12:46:30	4	4,500	1,017	-240	561	-310	725	-312	729	-334	-372	-353	826	-224	-310	-267	624	-246	-207	-227	530	-254	594
2L -3	12:50:30	8	4,500	1,017	-242	565	-313	731	-314	735	-337	-378	-357	835	-226	-316	-271	633	-250	-211	-231	540	-256	598
2U -1	12:53:00	1	3,000	679	-219	511	-274	640	-258	602	-244	-277	-261	610	-176	-251	-213	499	-207	-172	-190	444	-229	536
2U -1	12:54:00	2	3,000	679	-218	510	-272	637	-255	597	-243	-275	-259	606	-174	-249	-212	495	-206	-171	-188	440	-227	532
2U -1	12:55:00	3	3,000	679	-217	508	-272	637	-255	597	-243	-275	-259	606	-174	-248	-211	494	-205	-170	-188	439	-226	528
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2U -2	12:59:00	2	2,000	454	-186	435	-223	522	-198	462	-176	-199	-187	438	-135	-195	-165	386	-171	-137	-154	359	-203	475
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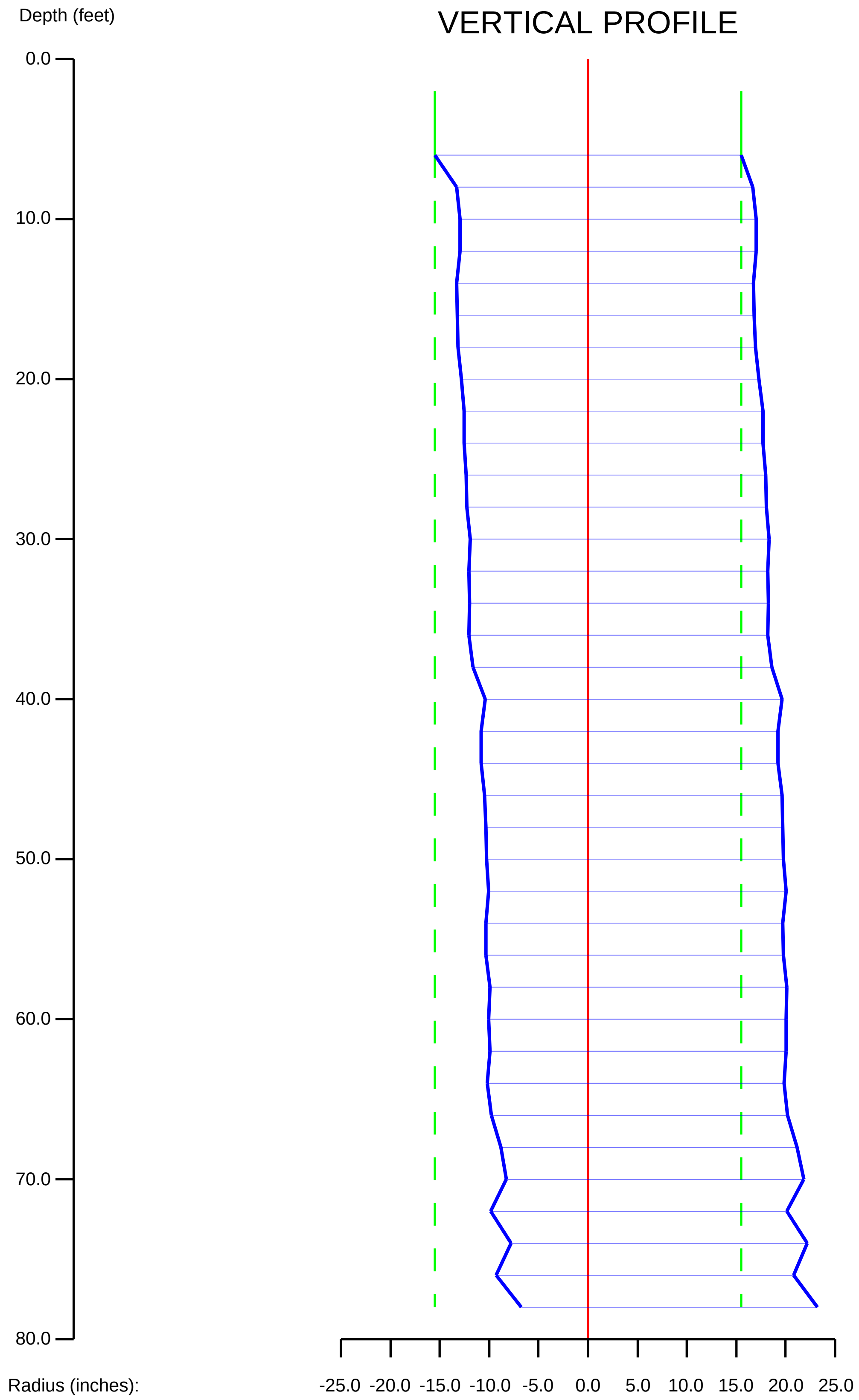
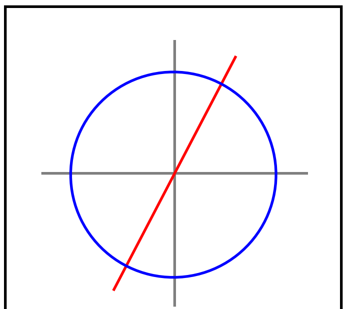
2U -3	13:02:30	1	1,000	229	-141	329	-162	378	-138	323	-112	-126	-119	278	-95	-139	-117	273	-132	-100	-116	271	-174	408
2U -3	13:03:30	2	1,000	229	-139	325	-160	375	-136	319	-110	-124	-117	274	-94	-137	-115	270	-131	-99	-115	269	-173	405
2U -3	13:04:30	3	1,000	229	-138	323	-159	373	-135	317	-109	-122	-116	270	-93	-136	-114	267	-130	-98	-114	267	-172	403
2U -3	13:05:30	4	1,000	229	-138	322	-158	369	-134	313	-107	-120	-114	266	-92	-134	-113	264	-129	-97	-113	264	-171	401
2U -4	13:08:00	1	500	117	-104	244	-117	274	-96	224	-65	-72	-69	161	-80	-90	-85	200	-96	-67	-82	191	-143	335
2U -4	13:09:00	2	500	117	-104	243	-117	274	-97	227	-67	-74	-71	165	-83	-91	-87	204	-97	-68	-82	192	-143	334
2U -4	13:10:00	3	500	117	-104	243	-118	275	-97	228	-68	-75	-72	167	-83	-92	-88	205	-97	-68	-83	194	-143	334
2U -4	13:11:00	4	500	117	-104	244	-118	276	-98	229	-69	-77	-73	170	-83	-93	-88	206	-98	-69	-84	196	-143	335
2U -5	13:13:30	1	0	0	-71	166	-77	180	-60	140	-26	-27	-27	62	-36	-45	-41	95	-61	-37	-49	114	-108	253
2U -5	13:14:30	2	0	0	-70	164	-76	178	-59	139	-25	-26	-26	60	-35	-44	-40	92	-60	-36	-48	112	-107	250
2U -5	13:16:30	4	0	0	-70	163	-75	176	-58	137	-24	-25	-24	57	-39	-43	-41	95	-59	-35	-47	110	-106	247
2U -5	13:20:30	8	0	0	-69	160	-75	175	-58	136	-23	-24	-23	55	-29	-42	-35	82	-59	-34	-47	109	-105	246

TexDOT UT ADSC - TS-2

Austin, TX, 9/11/2012

VERTICAL PROFILE





Section alignment 208.0º

Project Number: 9981-2

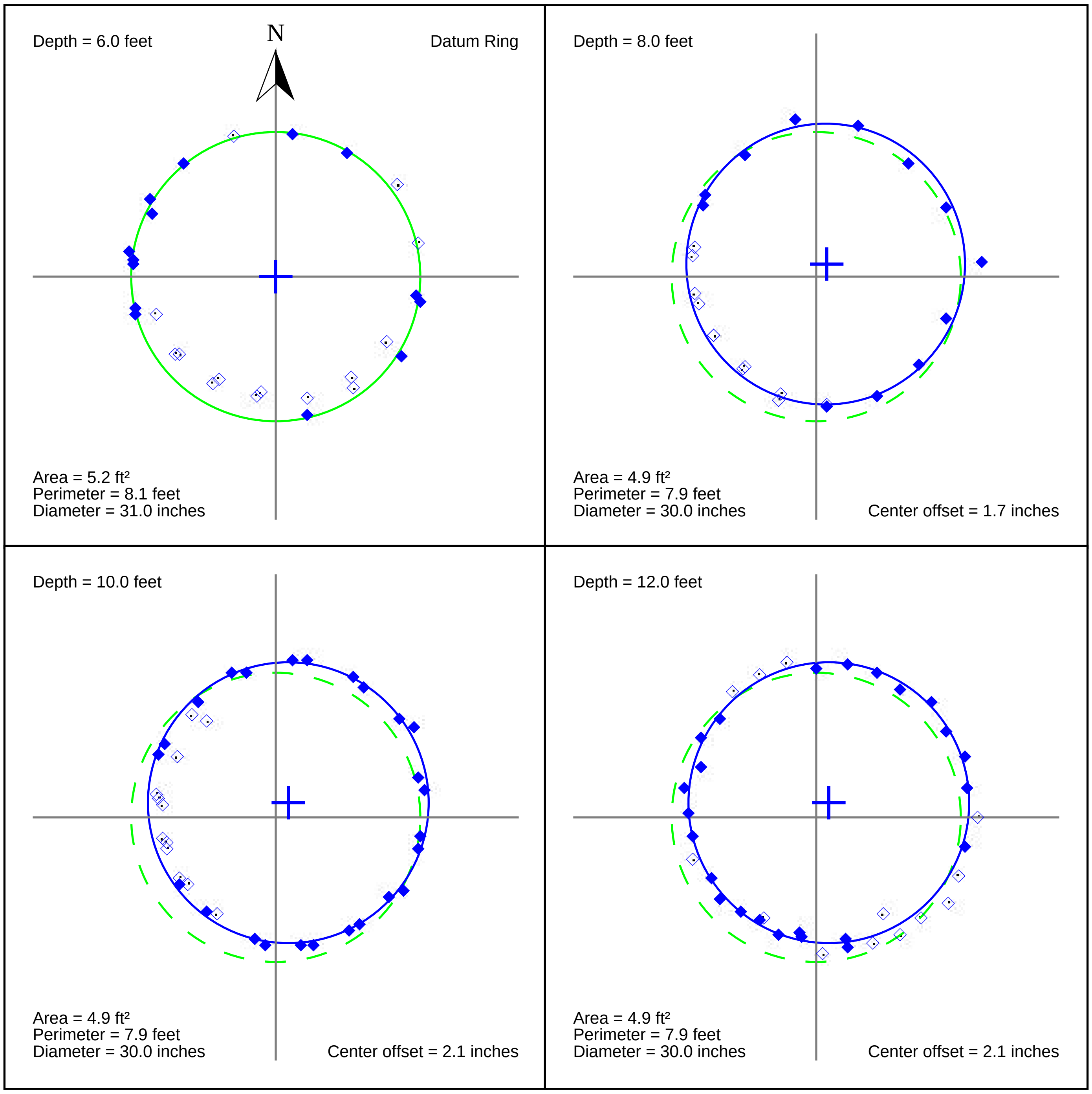
TexDOT UT ADSC - TS-2

Austin, TX, 9/11/2012

Project Number: 9981-2

TexDOT UT ADSC - TS-2

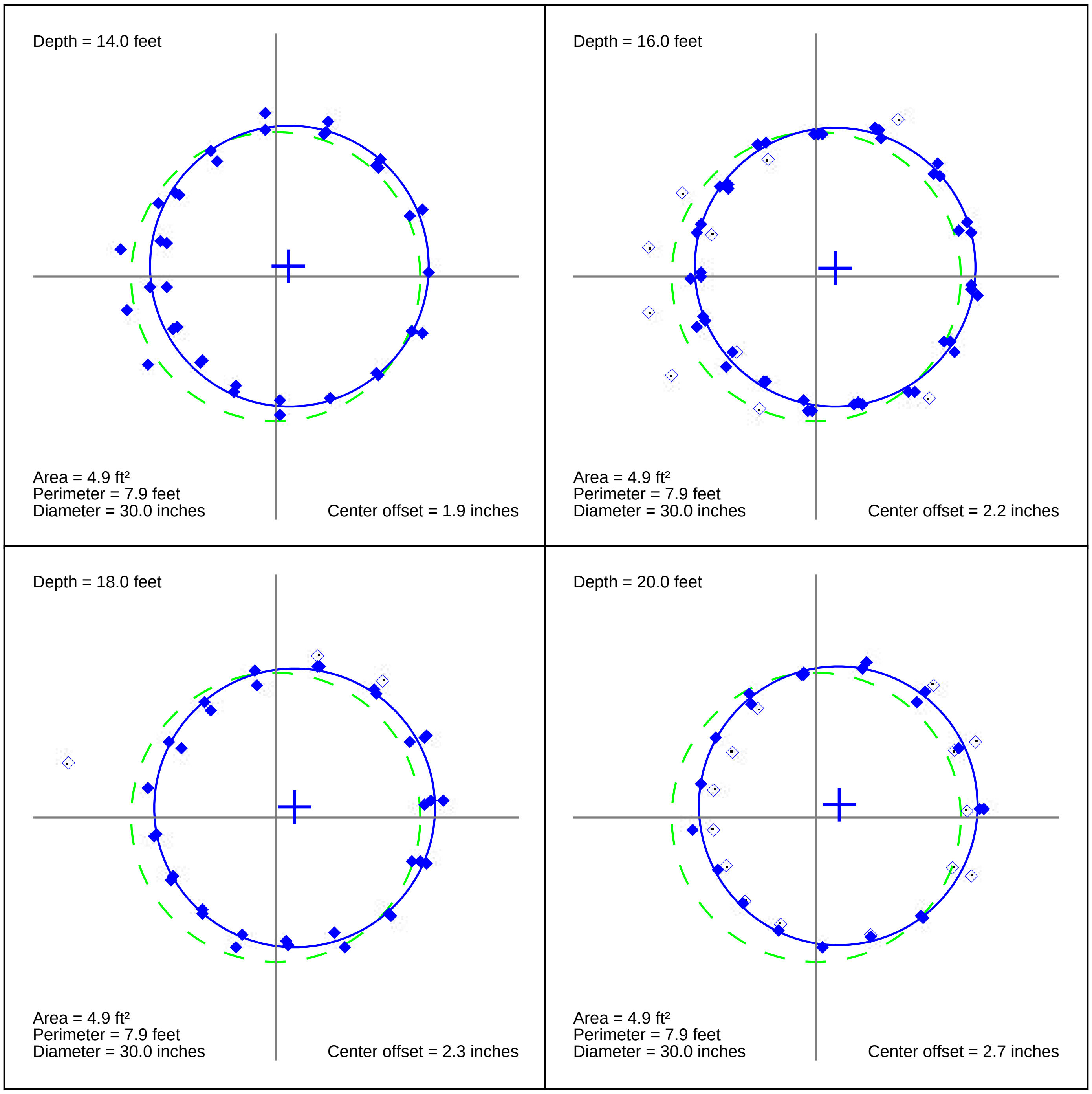
Austin, TX, 9/11/2012



LOADTEST Project Number: 9981-2 SONICALIPER

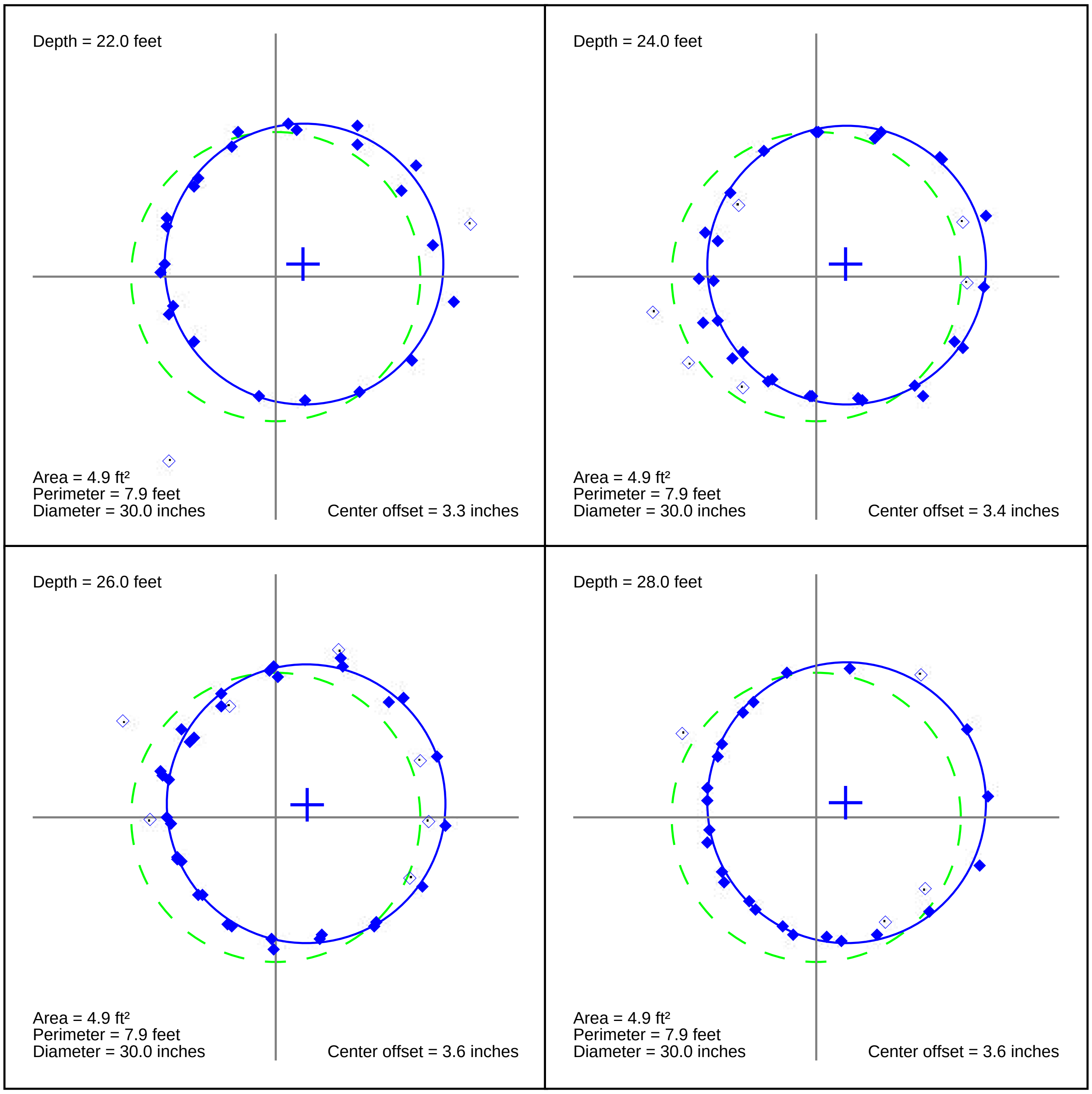
TexDOT UT ADSC - TS-2

Austin, TX, 9/11/2012



TexDOT UT ADSC - TS-2

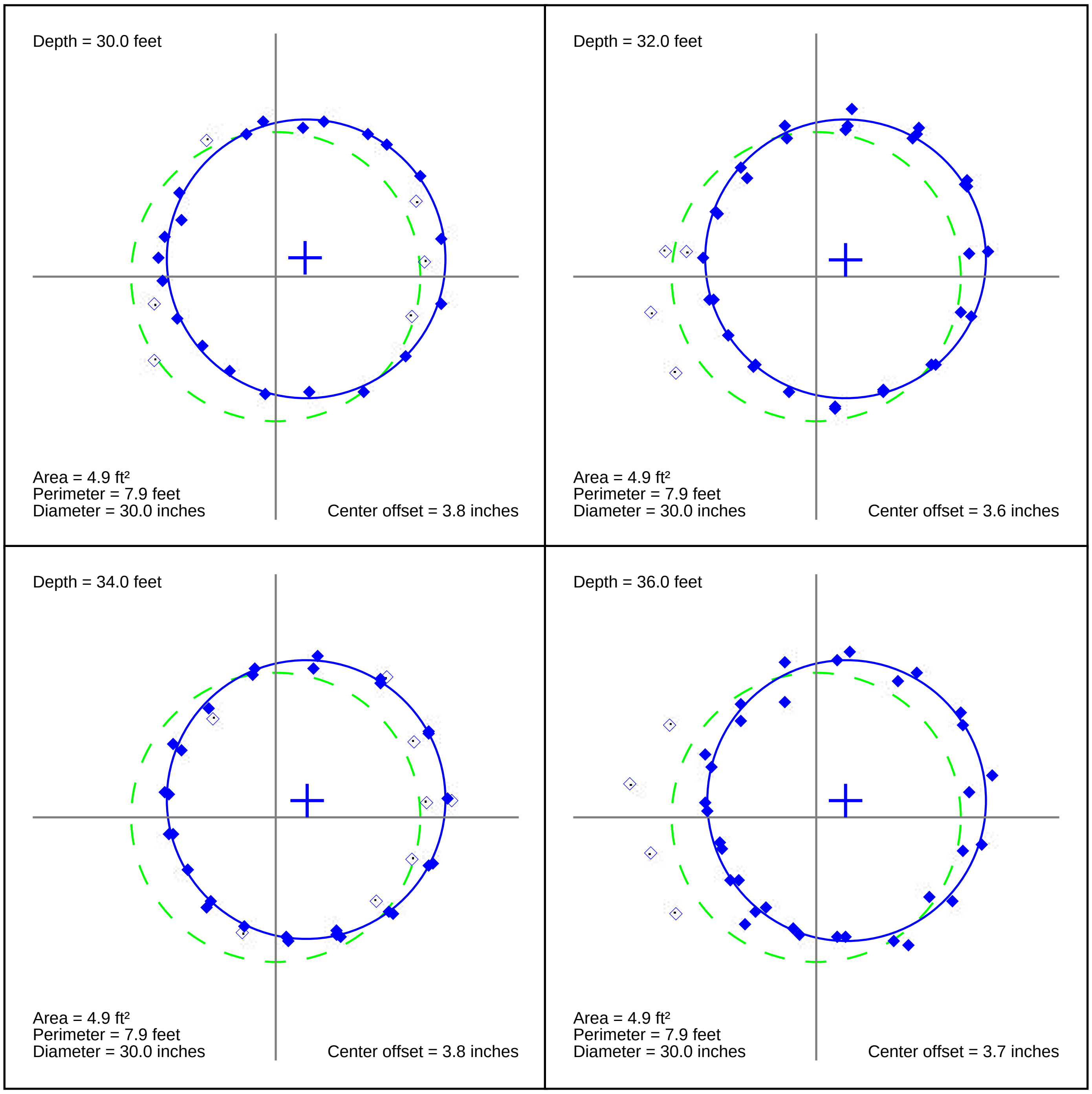
Austin, TX, 9/11/2012



Project Number: 9981-2

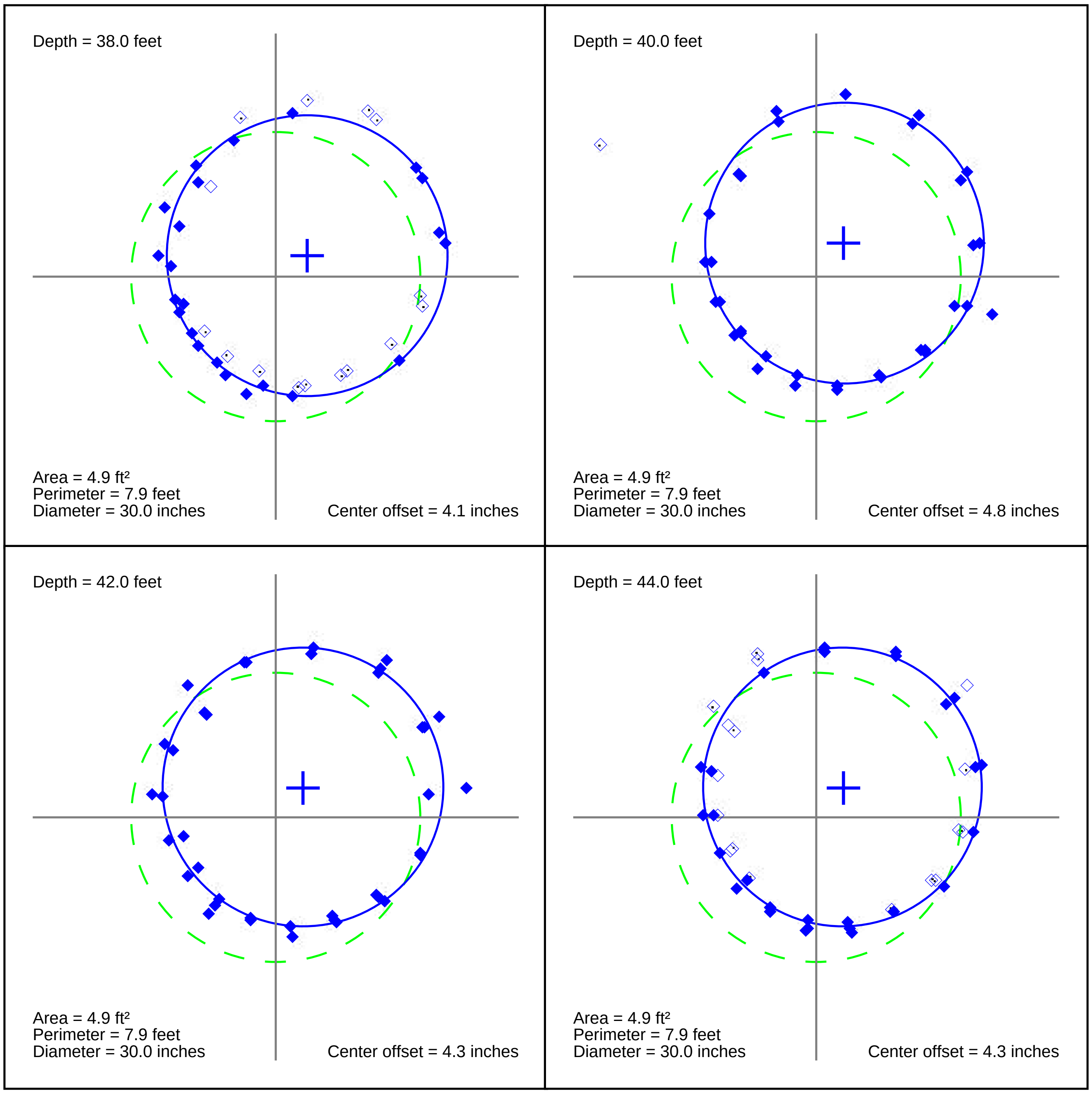
TexDOT UT ADSC - TS-2

Austin, TX, 9/11/2012



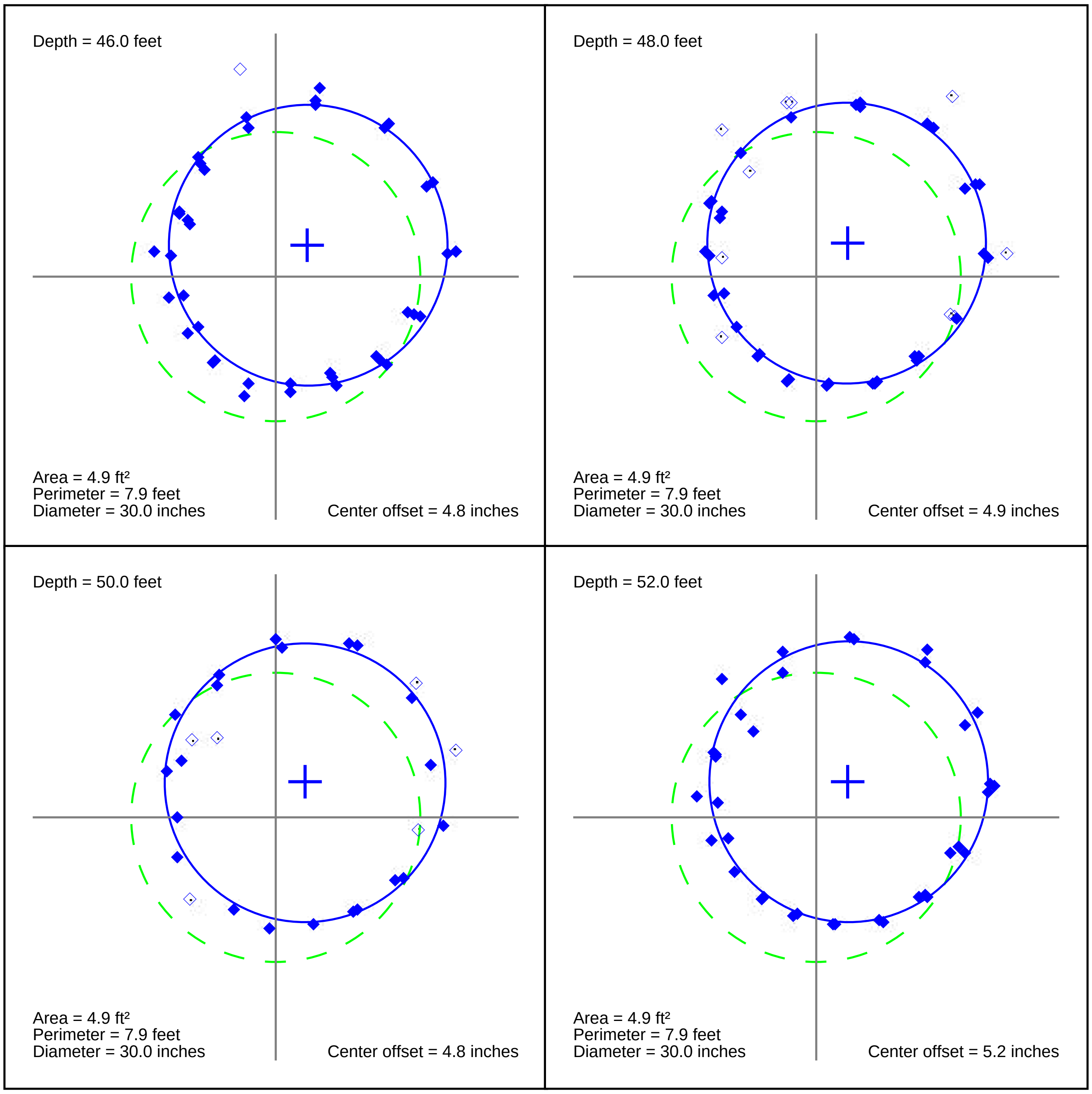
TexDOT UT ADSC - TS-2

Austin, TX, 9/11/2012



TexDOT UT ADSC - TS-2

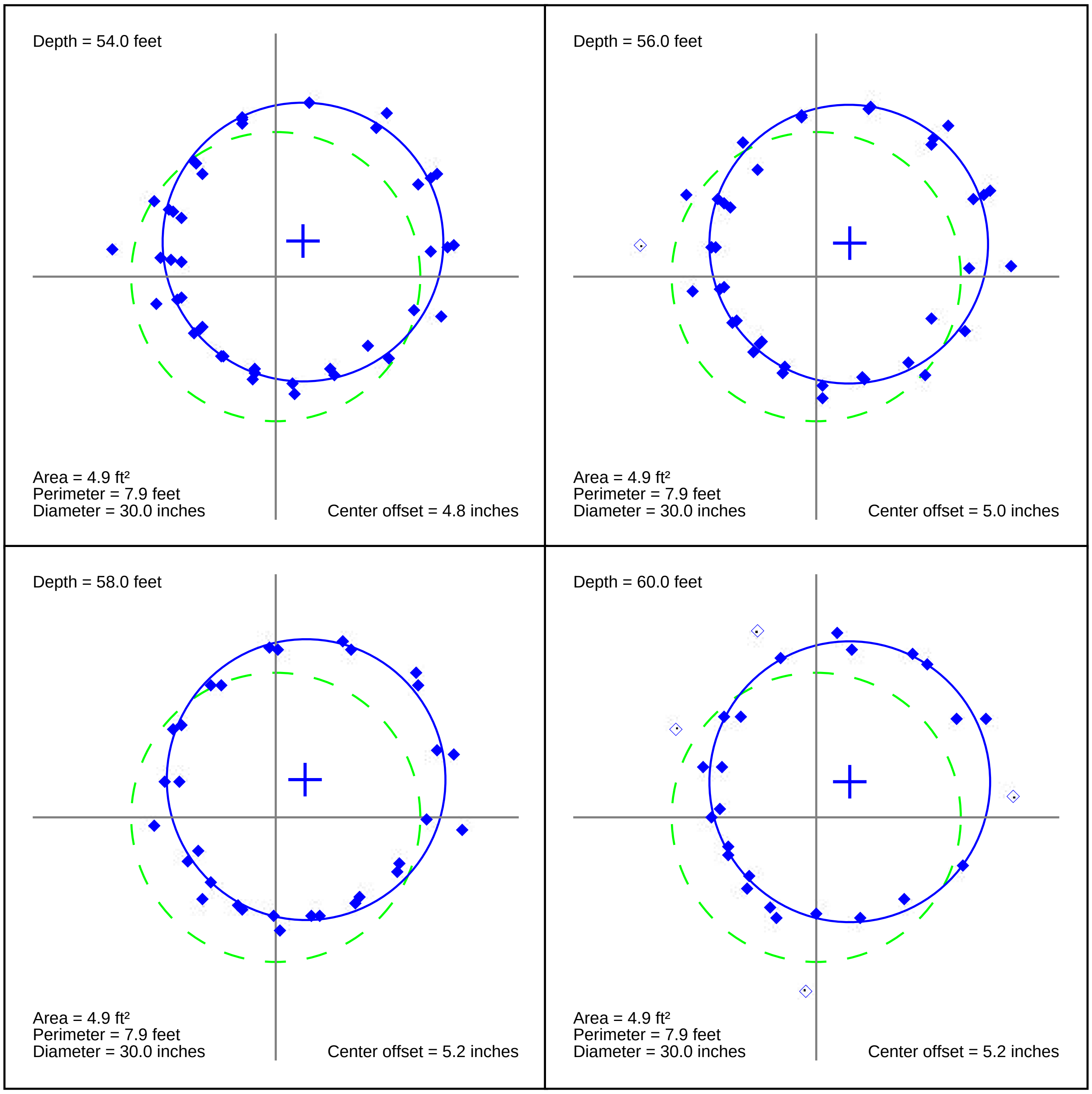
Austin, TX, 9/11/2012



LOADTEST Project Number: 9981-2 SONICALIPER

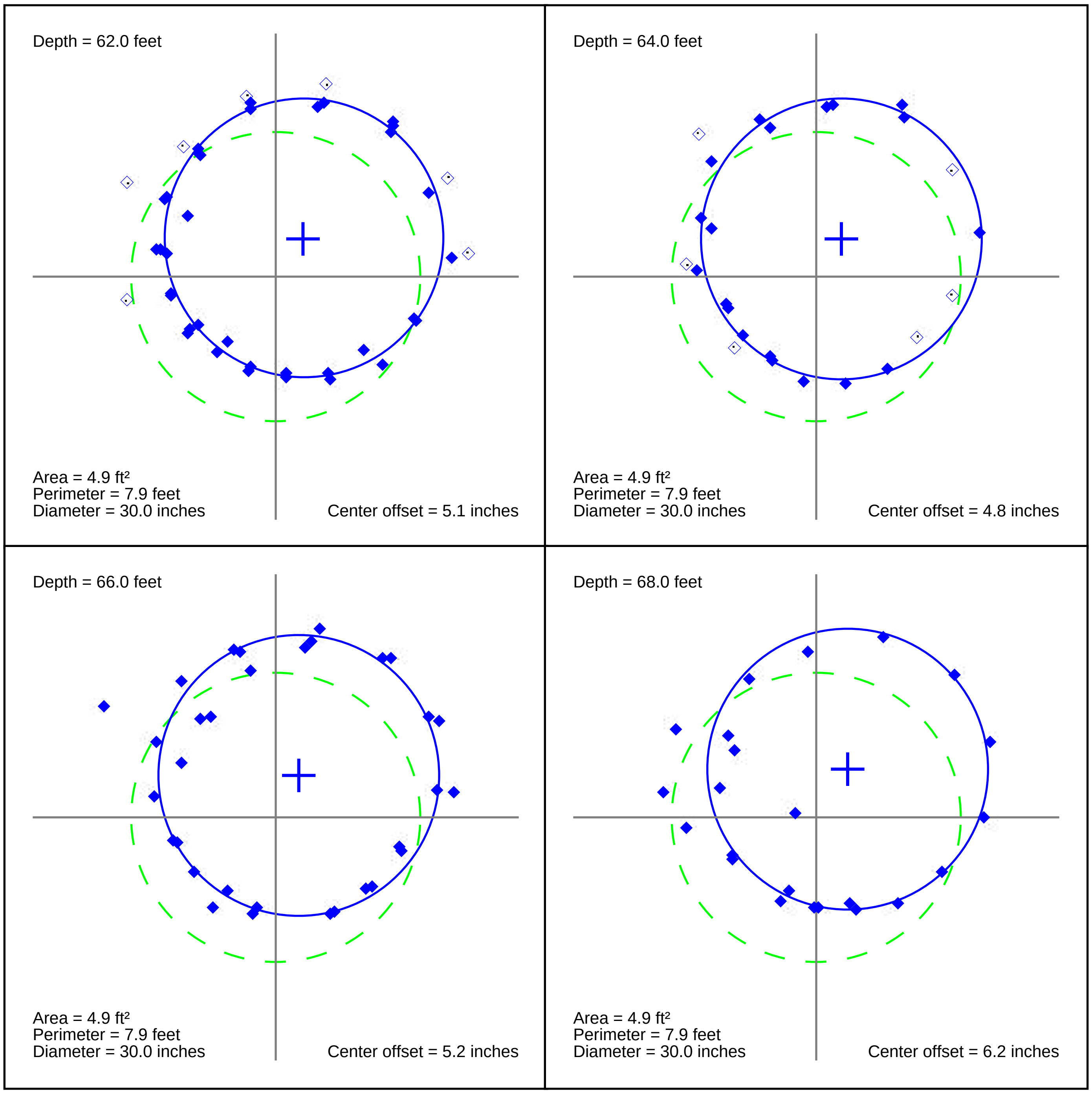
TexDOT UT ADSC - TS-2

Austin, TX, 9/11/2012



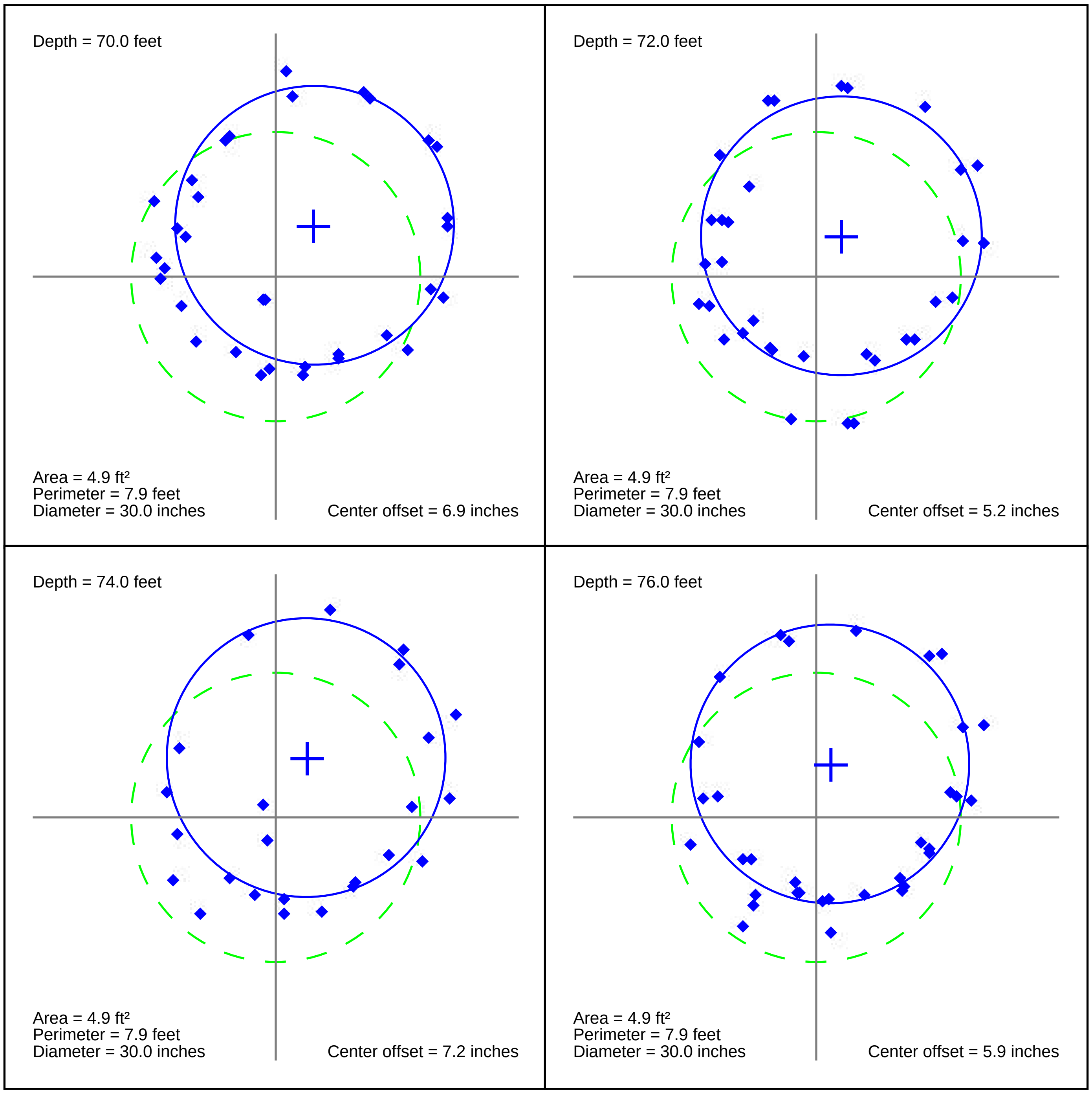
TexDOT UT ADSC - TS-2

Austin, TX, 9/11/2012



TexDOT UT ADSC - TS-2

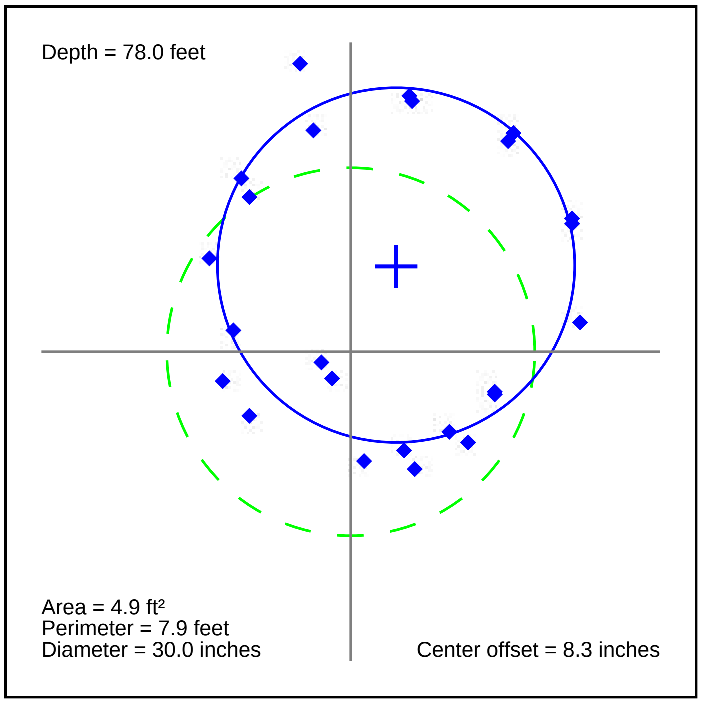
Austin, TX, 9/11/2012



LOADTEST Project Number: 9981-2 SONICALIPER

TexDOT UT ADSC - TS-2

Austin, TX, 9/11/2012



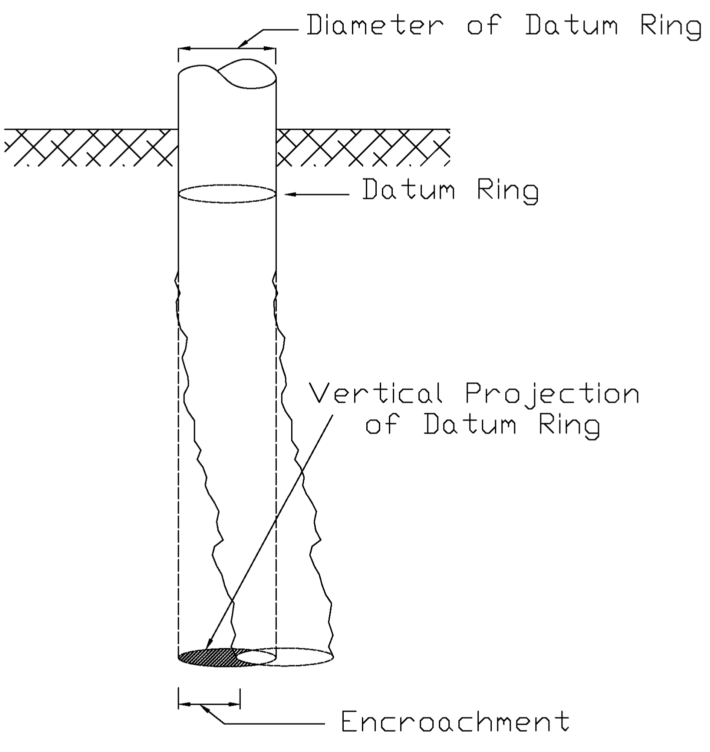
INTERPRETATION OF SONICALIPER FIELD DATA REPORT

General: The SoniCaliper is a profiling sonar device, specially adapted to function in drilling fluids. Each 360° pass generated with the SoniCaliper device produces up to one hundred twenty individual echo returns (profile data points). In the preceding figures (profile ring plots), the diamond points represent individual profile data points. A geometric shape is fitted to the data points using an iterative least-squares technique to approximate the cross-sectional profile of the shaft for verticality, perimeter area and volume calculations. Hollow diamonds designate points that are not used in the data fitting.

Deployment: The device is lowered into the shaft excavation in incremental depths. At each depth, a 360° sweep of the shaft wall is performed. The device is assumed to hang vertically in the shaft (any deviation from verticality can be noted using onboard pitch and roll sensors). Any twist in the device relative to its initial orientation is compensated by onboard compass and/or gyroscope sensors.

Calibration: Because the properties of drilling fluids vary widely, a calibration must be performed for each shaft to determine fluid wavespeed. This is done by selecting a profile ring of known diameter (usually, but not always the upper-most profile ring) as the “calibration ring”. The data analysis then back-calculates the fluid wavespeed based on the known diameter of this ring. The fluid wavespeed is assumed to be constant over the entire column of fluid depth.

Shaft Verticality: To determine shaft verticality, a profile ring (usually, but not always the calibration ring) is selected as the “datum ring”. The geometric centers of the datum ring and all other profile rings are compared. The “center offset” listed on the figures indicates the divergence of each profile ring center point from the datum ring center point. “Encroachment” is presented graphically as the shaded area representing the portion of the shaft wall which would encroach into the perfectly vertical projection of the datum ring to the depth in question. The maximum encroachment value for each profile ring is also given numerically. The user may choose to display computed values for the vertical inclination of the shaft between each ring and the datum ring, for both encroachment and center offset. Inclination may be expressed as a percentage or as a deviation:depth ratio.



Calipered Volume: The cross sectional area of each profile ring is determined and a cumulative volume for the calipered portion of the shaft is calculated. Note that this volume is a minimum.

REPORT OF CONCRETE CYLINDER COMPRESSION TESTS

Fugro Consultants, Inc.
8613 Cross Park Drive
Austin, Texas 78754
Phone (512) 977-1800
Fax (512) 973-9966

Project: UT O-Cell Install
Date Cast: 09/12/12
Job No.: 04.30121045
Cast By: Stuart Terwilliger
Report Date: 10/10/2012

Mix Design Data Mix No. CXSS8B08

Concrete Supplier: TXI
Approved Uses: None

Location of Placement: UT Test Pier, 0-611, Install Next to Highway 71
Truck No.: 5008 Ticket No.: 1402934 Time Batched: 816 Time Placed: 910

	Properties of Fresh Concrete	Specifications
Ambient Temp. (°F):	78	
Concrete Temp. (°F), ASTM 1064:	76	
Slump (inches), ASTM C143:	9 1/2	-- to --"
Air Content by Volumemetric Method (%), ASTM C173:	--	-- to --%
Air Content By Pressure Method (%), ASTM C231:	--	-- to --%
Plastic Unit Weight (pcf), ASTM C138:	--	
Water Added on Site, (gal):	--	

Laboratory Test Results

Specified Strength: 4,500 psi at 28 days

Laboratory No.	Date Tested	Age, Days	Diameter inches	Area sq in.	Total Load, lbs.	Compressive Strength, psi	Percent of Design	Fracture Type	
SCT0912120910 A	9/19/2012	7	6.00	28.27	85,570	3,030	67%	2	**
SCT0912120910 B	9/21/2012	9	6.00	28.27	98,650	3,490	78%	5	
SCT0912120910 B	10/10/2012	28	6.00	28.27	143,020	5,060	112%	5	
SCT0912120910 C	10/10/2012	28	6.00	28.27	147,550	5,220	116%	5	
SCT0912120910 D	11/7/2012	56	6.00	28.27		-	-	-	

NOTES:

1. Cylinders are standard 6 in. dia. by 12 in. height, molded in accordance with ASTM C31, delete Para.10.1.2
2. Fresh concrete and molded specimen were tested in accordance with ASTM C39, C172, and C1231.
3. Fracture Types: 1) cone, 2) cone & split, 3) columnar, 4) diagonal, 5) corner fracture, 6) multiple corner fractures
4. Batch plant inspection not performed.

** Denotes 7-Day test did not reach 70% of the Specified Strength.

DISTRIBUTION:

Submitted by: Fugro Consultants, Inc.
TBPE Firm Registration No. 299

PM

10/10/12

John S. Landwermeyer, P.E.

STATE OF TEXAS
JOHN S. LANDWERMEYER
79751
LICENSED
PROFESSIONAL ENGINEER

THE ABOVE TEST RESULTS APPLY ONLY TO THE ITEMS TESTED.
THIS REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL WITHOUT THE APPROVAL OF FUGRO.

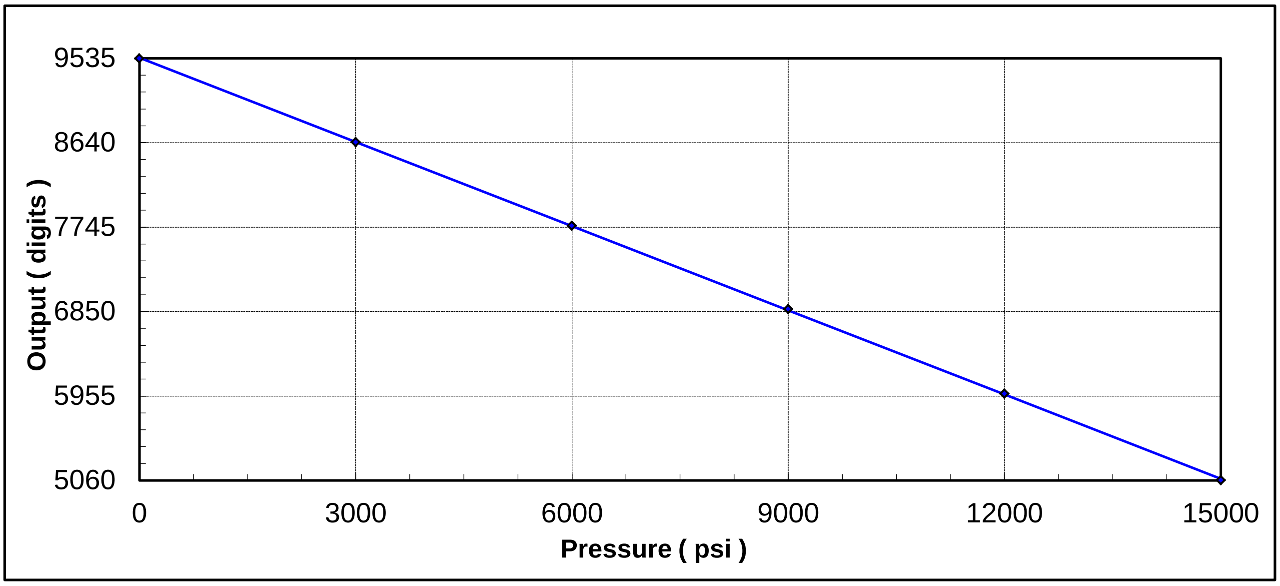
Appendix D: Instrumentation Calibration Certificates

Instrumentation Used on Test Shaft #1

Certificate of Calibration

Instrument:	Geokon VW PX	Calibration Date:	March 12, 2012
Model:	4500HH-100MPa	Temperature:	21.1 °C
		Barometric Pressure:	102.2 kPa
Serial Number:	1124389	Linear Range:	15000 psi

Pressure (psi)	1st Cycle (digits)	2nd Cycle (digits)	Average (digits)	Calculated (psi)	Linearity (% FS)
0	9533	9535	9534	24.48	0.16
3000	8645	8644	8645	3013.54	0.09
6000	7762	7760	7761	5982.44	-0.12
9000	6875	6880	6878	8951.33	-0.32
12000	5972	5986	5979	11970.63	-0.20
15000	5060	5062	5061	15055.46	0.37



Linear Gauge Factor: -3.3604 **psi/dig** -0.0231690 **MPa/dig**

LOADTEST certifies that the above named instrument has been calibrated by comparison with standards traceable to the NIST and was found to be in tolerance in all operating ranges.

Tested by: Michael Crumpton, B.S.C.E. Signed: M Z Crumpton

Approved by: David J. Jakstis, P.E. Signed:

Certificate of Calibration

Instrument: Geokon LVWDT

Model: 4450-3X-100

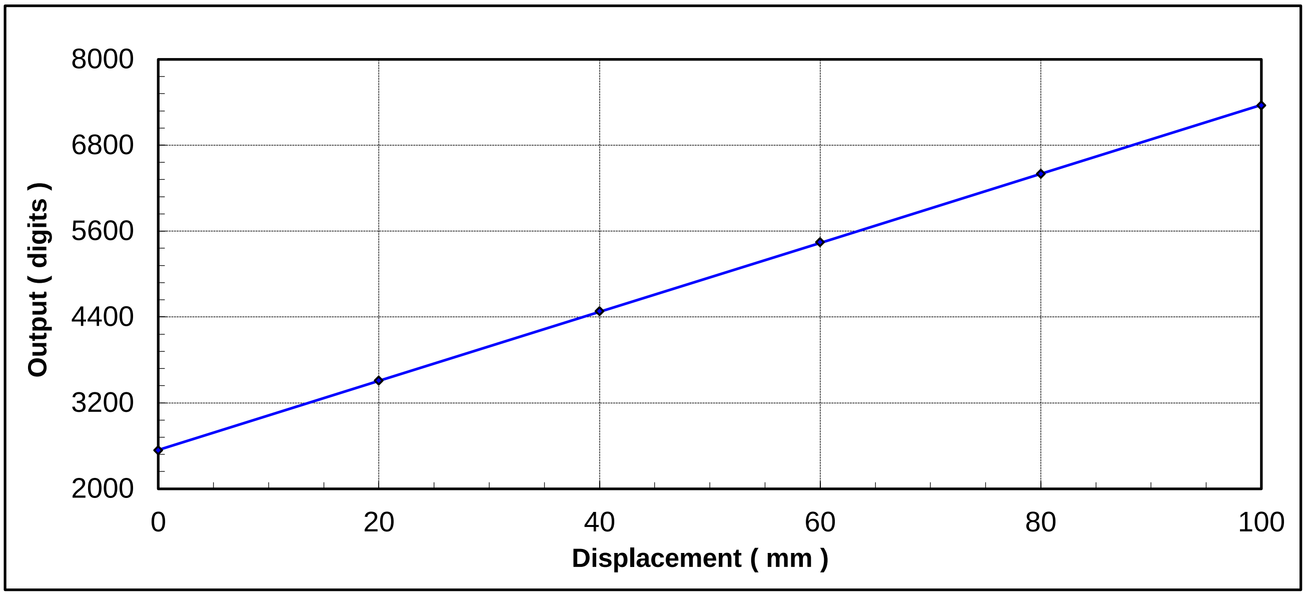
Serial Number: 1124298

Calibration Date: March 12, 2012

Temperature: 23.1 °C

Linear Range: 100 mm

Displacement (mm)	1st Cycle (digits)	2nd Cycle (digits)	Average (digits)	Calculated (mm)	Linearity (% FS)
0	2536	2529	2533	-0.20	-0.20
20	3512	3507	3509	20.06	0.06
40	4481	4476	4479	40.17	0.17
60	5441	5439	5440	60.12	0.12
80	6400	6397	6399	80.01	0.01
100	7355	7354	7354	99.84	-0.16



Linear Gauge Factor: 0.02075 **mm/dig** 0.0008168 **in/dig**

LOADTEST certifies that the above named instrument has been calibrated by comparison with standards traceable to the NIST and was found to be in tolerance in all operating ranges.

Tested by: Michael Crumpton, B.S.C.E. Signed: M Z Crumpton

Approved by: David J. Jakstis, P.E. Signed:

DEEP FOUNDATION TESTING, EQUIPMENT & SERVICES • SPECIALIZING IN OSTERBERG CELL (O-cell®) TECHNOLOGY
O-cell® is a registered trademark.

Certificate of Calibration

Instrument: Geokon LVWDT

Model: 4450-3X-100

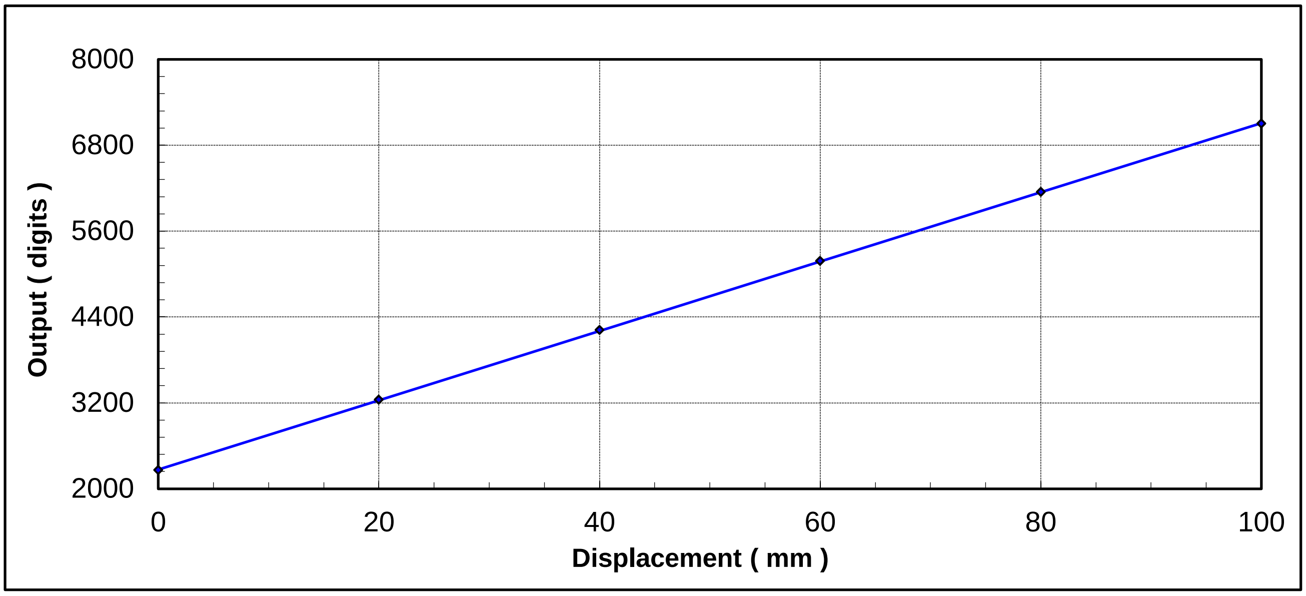
Serial Number: 1124297

Calibration Date: March 12, 2012

Temperature: 23.2 °C

Linear Range: 100 mm

Displacement (mm)	1st Cycle (digits)	2nd Cycle (digits)	Average (digits)	Calculated (mm)	Linearity (% FS)
0	2257	2258	2258	-0.24	-0.24
20	3241	3241	3241	20.08	0.08
40	4215	4214	4215	40.19	0.19
60	5181	5181	5181	60.15	0.15
80	6143	6143	6143	80.02	0.02
100	7100	7101	7101	99.80	-0.20



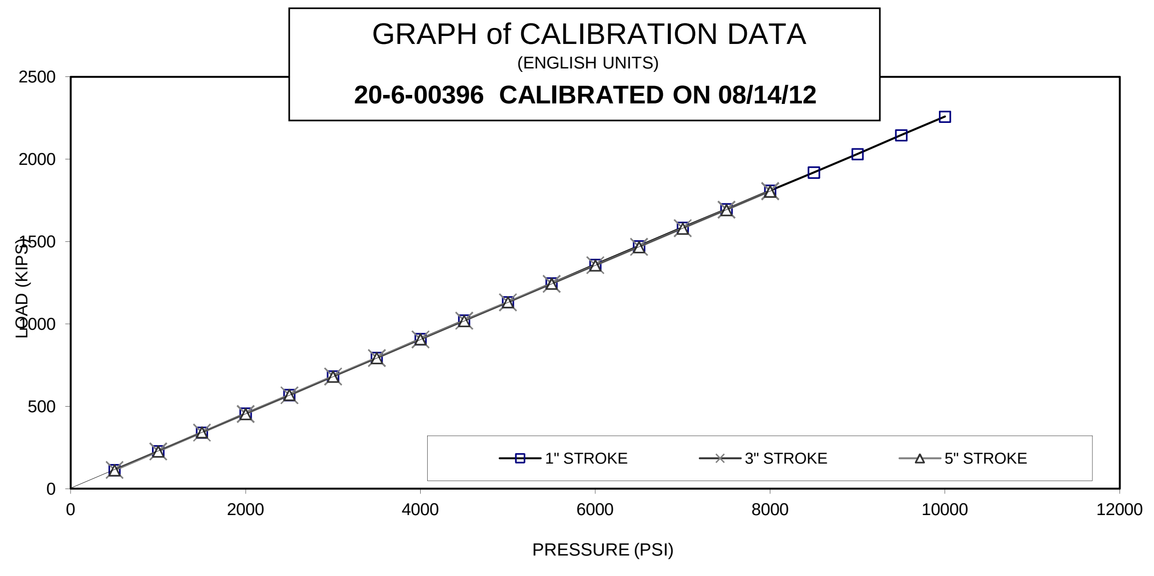
Linear Gauge Factor: **0.02066** **mm/dig** **0.0008132** **in/dig**

LOADTEST certifies that the above named instrument has been calibrated by comparison with standards traceable to the NIST and was found to be in tolerance in all operating ranges.

Tested by: Michael Crumpton, B.S.C.E. Signed: M Z Crumpton

Approved by: David J. Jakstis, P.E. Signed:

AMERICAN EQUIPMENT FABRICATING CORP



20" O-CELL, SERIAL # 20-6-00396

STROKE:	1 INCH	3 INCH	5 INCH
PRESSURE PSI	LOAD KIPS	LOAD KIPS	LOAD KIPS
0	0	0	0
500	113	115	113
1000	228	227	228
1500	341	341	342
2000	457	454	454
2500	569	568	569
3000	682	682	681
3500	795	794	794
4000	908	907	907
4500	1021	1020	1019
5000	1132	1132	1132
5500	1246	1244	1245
6000	1360	1357	1355
6500	1472	1469	1467
7000	1585	1582	1580
7500	1696	1694	1692
8000	1809	1807	1804
8500	1919		
9000	2031		
9500	2145		
10000	2258		

LOAD CONVERSION FORMULA

LOAD = PRESSURE * 0.2255 + (3.73)
{KIPS} {PSI}

Regression Output:

Constant	3.7300	kips
X Coefficient	0.2255	kip / psi
R Square	1.0000	
No. of Observations	52	
Degrees of Freedom	50	
Std Err of Y Est	1.80	
Std Err of X Coeff	0.0001	

CALIBRATION STANDARDS:

All data presented are derived from 6" dia. certified hydraulic pressure gauges and electronic load transducer, manufactured and calibrated by the University of Illinois at Champaign, Illinois. All calibrations and certifications are traceable through the Laboratory Master Deadweight Gauges directly to the National Institute of Standards and Technology. No specific guidelines exist for calibration of load test jacks and equipment but procedures comply with similar guidelines for calibration of gages, ANSI specifications B40.1.

* AE & FC CUSTOMER: LOADTEST INC.	* CONTRACTOR.: McKINNEY DRILLING
* AE & FC JOB NO: SO9202	* JOB LOCATION: BUDA, TX
* CUSTOMER P.O. NO.: LT-9981-1	* DATED: 08/14/12

SERVICE ENGINEER: [signature] DATE: 8-14-12

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Displacement Transducer Calibration Report

Range: 150 mm

Calibration Date: August 15, 2012

Serial Number: 1218849

Temperature: 23.7 °C

Calibration Instruction: CI-4400

Technician:

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2437	2432	2435	-0.26	-0.17	0.04	0.03
30.0	3423	3422	3423	30.00	0.00	29.93	-0.05
60.0	4411	4408	4410	60.22	0.15	59.97	-0.02
90.0	5393	5391	5392	90.31	0.21	90.06	0.04
120.0	6365	6363	6364	120.08	0.05	120.02	0.01
150.0	7328	7332	7330	149.67	-0.22	149.97	-0.02

(mm) Linear Gage Factor (G): 0.03063 (mm/ digit) **Regression Zero: 2443**

Polynomial Gage Factors: **A: 9.6906E-08** **B: 0.02968** **C:**

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

(inches) Linear Gage Factor (G): 0.001206 (inches/digit)

Polynomial Gage Factors: **A: 3.8152E-09** **B: 0.001168** **C:**

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

Refer to manual for temperature correction information.

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Displacement Transducer Calibration Report

Range: 150 mm

Calibration Date: August 15, 2012

Serial Number: 1218850

Temperature: 23.7 °C

Calibration Instruction: CI-4400

Technician:

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2421	2420	2421	-0.29	-0.19	-0.02	-0.02
30.0	3410	3408	3409	30.08	0.05	30.03	0.02
60.0	4392	4390	4391	60.25	0.16	60.04	0.03
90.0	5366	5364	5365	90.17	0.11	89.96	-0.02
120.0	6337	6336	6337	120.02	0.01	119.97	-0.02
150.0	7306	7303	7305	149.76	-0.16	150.02	0.02

(mm) Linear Gage Factor (G): 0.03072 (mm/ digit)

Regression Zero: 2430

Polynomial Gage Factors: A: 8.3139E-08 B: 0.02991 C: ______

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

(inches) Linear Gage Factor (G): 0.001210 (inches/digit)

Polynomial Gage Factors: A: 3.2732E-09 B: 0.001178 C: ______

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

Refer to manual for temperature correction information.

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Displacement Transducer Calibration Report

Range: 150 mm

Calibration Date: August 15, 2012

Serial Number: 1218851

Temperature: 23.7 °C

Calibration Instruction: CI-4400

Technician:

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2448	2446	2447	-0.28	-0.18	-0.03	-0.02
30.0	3434	3432	3433	30.04	0.03	30.01	0.01
60.0	4415	4416	4416	60.25	0.17	60.08	0.06
90.0	5388	5386	5387	90.13	0.09	89.96	-0.03
120.0	6357	6357	6357	119.96	-0.03	119.93	-0.05
150.0	7328	7327	7328	149.80	-0.13	150.05	0.03

(mm) Linear Gage Factor (G): 0.03075 (mm/ digit)

Regression Zero: 2456

Polynomial Gage Factors: A: 7.3539E-08 B: 0.03003 C:

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

(inches) Linear Gage Factor (G): 0.001211 (inches/digit)

Polynomial Gage Factors: A: 2.8952E-09 B: 0.001182 C:

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

Refer to manual for temperature correction information.

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Displacement Transducer Calibration Report

Range: 150 mm

Calibration Date: August 15, 2012

Serial Number: 1218852

Temperature: 23.7 °C

Calibration Instruction: CI-4400

Technician:

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2397	2395	2396	-0.28	-0.18	-0.02	-0.01
30.0	3387	3381	3384	30.07	0.05	30.01	0.01
60.0	4367	4366	4367	60.24	0.16	60.03	0.02
90.0	5344	5342	5343	90.23	0.16	90.02	0.02
120.0	6312	6310	6311	119.96	-0.02	119.91	-0.06
150.0	7281	7283	7282	149.78	-0.14	150.04	0.03

(mm) Linear Gage Factor (G): 0.03071 (mm/ digit)

Regression Zero: 2405

Polynomial Gage Factors: A: 8.2168E-08 B: 0.02992 C: ________

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

(inches) Linear Gage Factor (G): 0.001209 (inches/digit)

Polynomial Gage Factors: A: 3.235E-09 B: 0.001178 C: ________

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

Refer to manual for temperature correction information.

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

Certificate of Calibration

Instrument: Geokon LVWDT

Model: 4450-3X-100

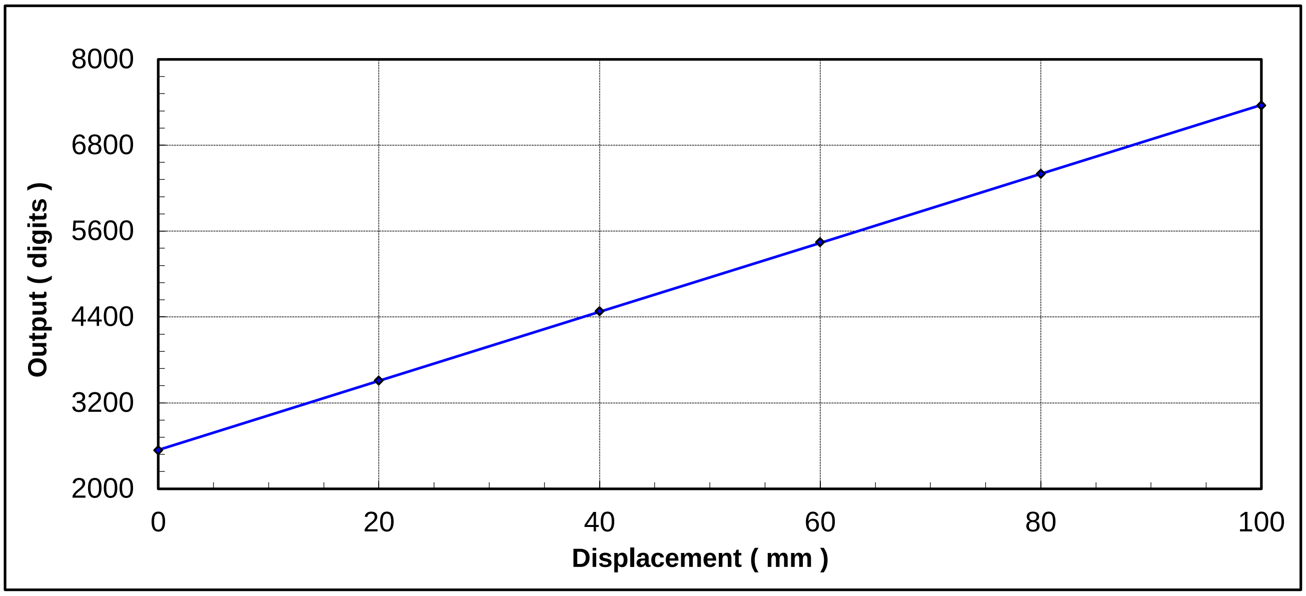
Serial Number: 1124298

Calibration Date: March 12, 2012

Temperature: 23.1 °C

Linear Range: 100 mm

Displacement (mm)	1st Cycle (digits)	2nd Cycle (digits)	Average (digits)	Calculated (mm)	Linearity (% FS)
0	2536	2529	2533	-0.20	-0.20
20	3512	3507	3509	20.06	0.06
40	4481	4476	4479	40.17	0.17
60	5441	5439	5440	60.12	0.12
80	6400	6397	6399	80.01	0.01
100	7355	7354	7354	99.84	-0.16



Linear Gauge Factor: 0.02075 **mm/dig** 0.0008168 **in/dig**

LOADTEST certifies that the above named instrument has been calibrated by comparison with standards traceable to the NIST and was found to be in tolerance in all operating ranges.

Tested by: Michael Crumpton, B.S.C.E. Signed: M Z Crumpton

Approved by: David J. Jakstis, P.E. Signed:

Certificate of Calibration

Instrument: Geokon LVWDT

Model: 4450-3X-100

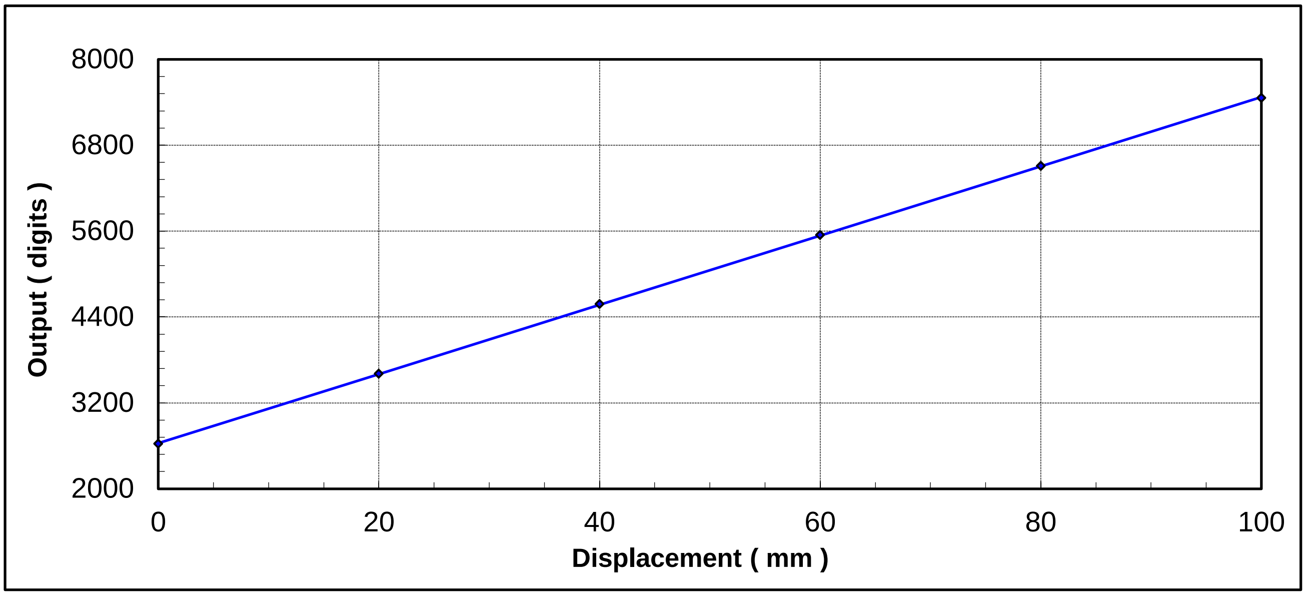
Serial Number: 1124299

Calibration Date: March 12, 2012

Temperature: 22.7 °C

Linear Range: 100 mm

Displacement (mm)	1st Cycle (digits)	2nd Cycle (digits)	Average (digits)	Calculated (mm)	Linearity (% FS)
0	2630	2622	2626	-0.18	-0.18
20	3603	3603	3603	20.03	0.03
40	4579	4573	4576	40.15	0.15
60	5545	5539	5542	60.11	0.11
80	6510	6509	6510	80.12	0.12
100	7464	7456	7460	99.77	-0.23



Linear Gauge Factor: 0.02068 **mm/dig** 0.0008140 **in/dig**

LOADTEST certifies that the above named instrument has been calibrated by comparison with standards traceable to the NIST and was found to be in tolerance in all operating ranges.

Tested by: Michael Crumpton, B.S.C.E. Signed: M Z Crumpton

Approved by: David J. Jakstis, P.E. Signed:

Certificate of Calibration

Instrument: Geokon LVWDT

Model: 4450-3X-100

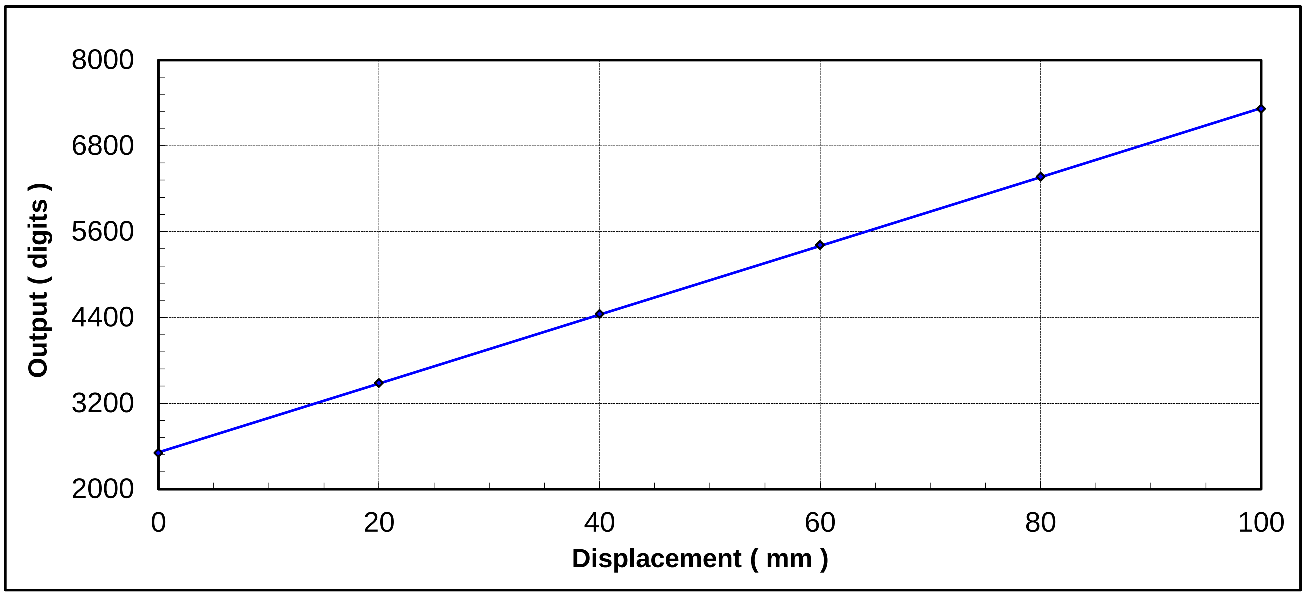
Serial Number: 1124300

Calibration Date: March 12, 2012

Temperature: 21.9 °C

Linear Range: 100 mm

Displacement (mm)	1st Cycle (digits)	2nd Cycle (digits)	Average (digits)	Calculated (mm)	Linearity (% FS)
0	2507	2502	2504	-0.21	-0.21
20	3482	3478	3480	20.06	0.06
40	4450	4445	4447	40.17	0.17
60	5410	5407	5409	60.14	0.14
80	6366	6364	6365	80.02	0.02
100	7320	7316	7318	99.81	-0.19



Linear Gauge Factor: 0.02078 **mm/dig** 0.0008182 **in/dig**

LOADTEST certifies that the above named instrument has been calibrated by comparison with standards traceable to the NIST and was found to be in tolerance in all operating ranges.

Tested by: Michael Crumpton, B.S.C.E. Signed: M Z Crumpton

Approved by: David J. Jakstis, P.E. Signed:

LYMON C. REESE & ASSOCIATES, INC.

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **101**

Strain Gauge:	C2A-06-250LW-350	**Linear Strain Range:**	+/-2,000με
Gauge Resistance (Ω):	350+/-0.6%	**Linear Temp. Range:**	-60ºF to +180ºF
Gauge Excitation:	2,500 mV (DC)	**Calibration Temp:**	24.9ºC
Gauge Factor (@24ºC):	2.105+/-0.5%	**Approx. Steel Bar OD (@Gage):**	0.344 in

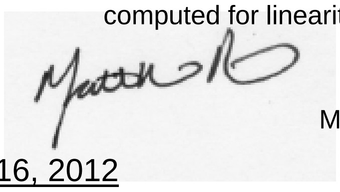
Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 101.2 feet

Connector Details: Turck "BS 8151-0/PG9" Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

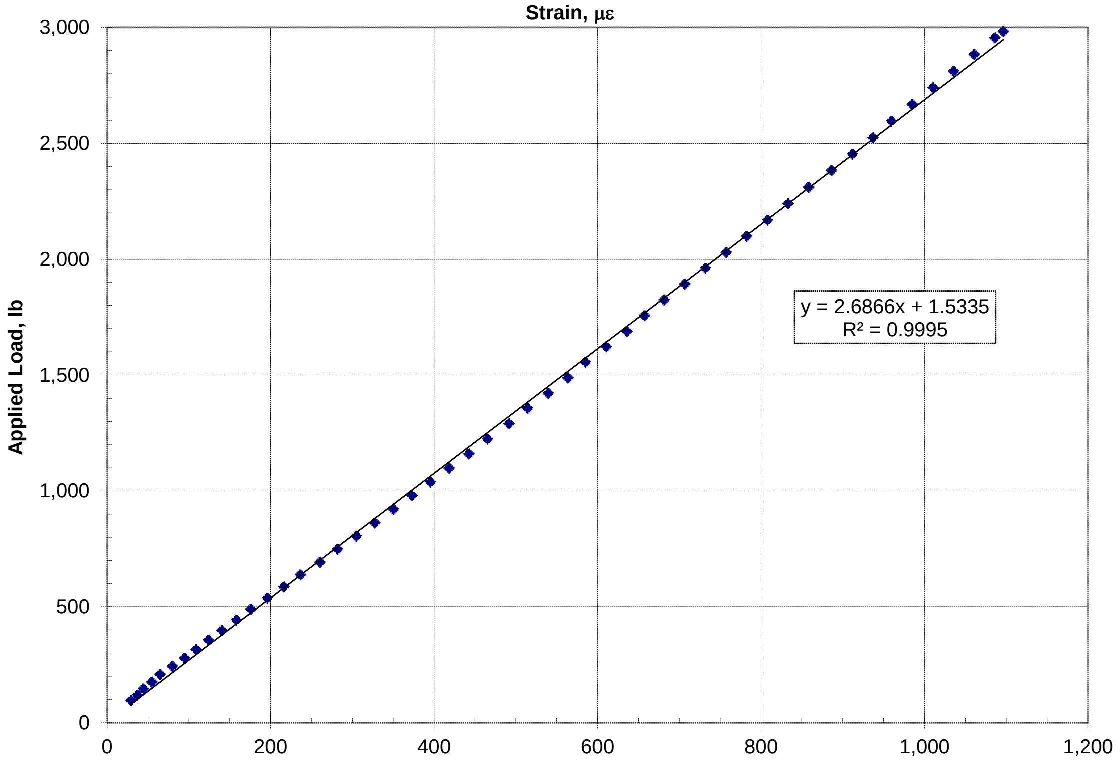
Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck "B 8151-0/PG9" mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, με; R^2 = statistical value, computed for linearity check of measurements

Calibrated By:  Matthew Price

Date: August 16, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 101 ********



Telephone: 512/244-6464 **Fax: 512/244-6067** **lcra@ensoftinc.com**

LYMON C. REESE & ASSOCIATES, INC.

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **103**

Strain Gauge: EA-06-125BZ-350
Gauge Resistance (Ω): 350+/-0.6%
Gauge Excitation: 2,500 mV (DC)
Gauge Factor (@24ºC): 2.115+/-0.5%

Linear Strain Range: +/-2,000με
Linear Temp. Range: -60ºF to +180ºF
Calibration Temp: 24.9ºC
Approx. Steel Bar OD (@Gage): 0.351 in

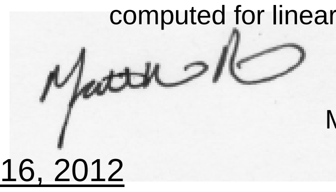
Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 101.9 feet

Connector Details: Turck “BS 8151-0/PG9” Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

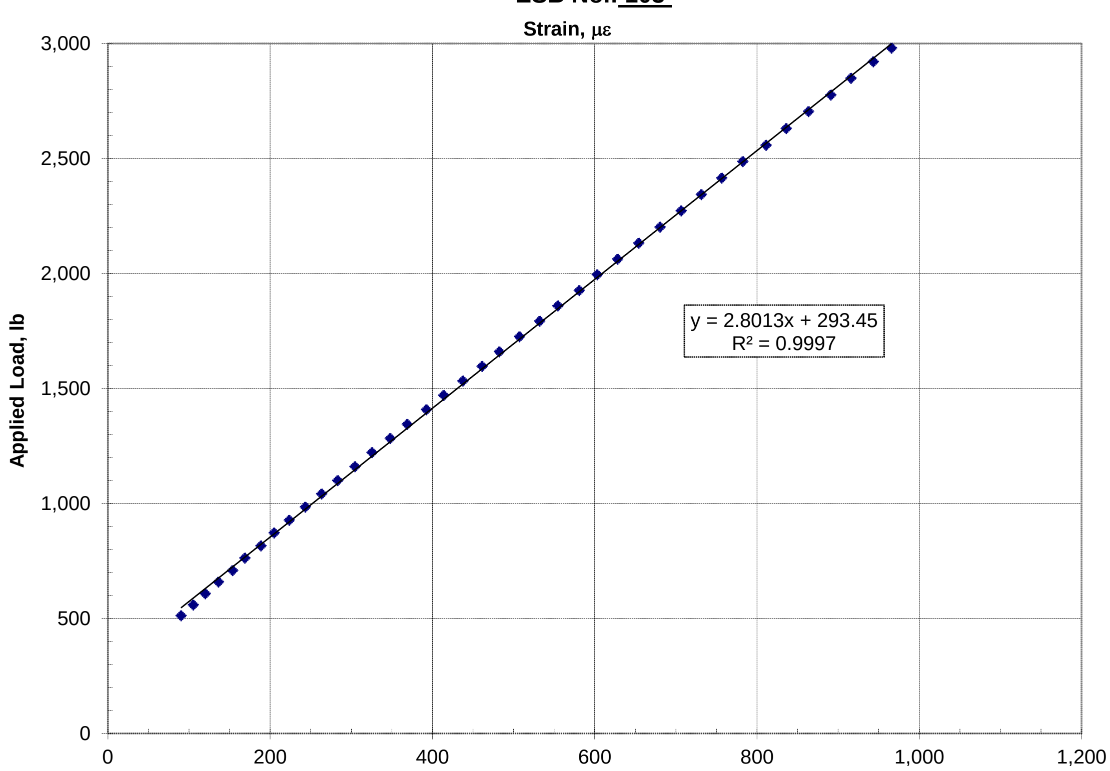
Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck “B 8151-0/PG9” mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, με; R^2 = statistical value, computed for linearity check of measurements

Calibrated By:  Matthew Price

Date: August 16, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 103 ********



Telephone: 512/244-6464 Fax: 512/244-6067 lcra@ensoftinc.com

LYMON C. REESE & ASSOCIATES, INC.

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **105**

Strain Gauge: EA-06-125BZ-350
Gauge Resistance (Ω): 350+/-0.6%
Gauge Excitation: 2,500 mV (DC)
Gauge Factor (@24ºC): 2.115+/-0.5%

Linear Strain Range: +/-2,000με
Linear Temp. Range: -60ºF to +180ºF
Calibration Temp: 24.8ºC
Approx. Steel Bar OD (@Gage): 0.347 in

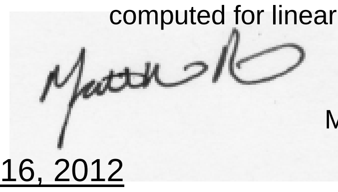
Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 102.5 feet

Connector Details: Turck "BS 8151-0/PG9" Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

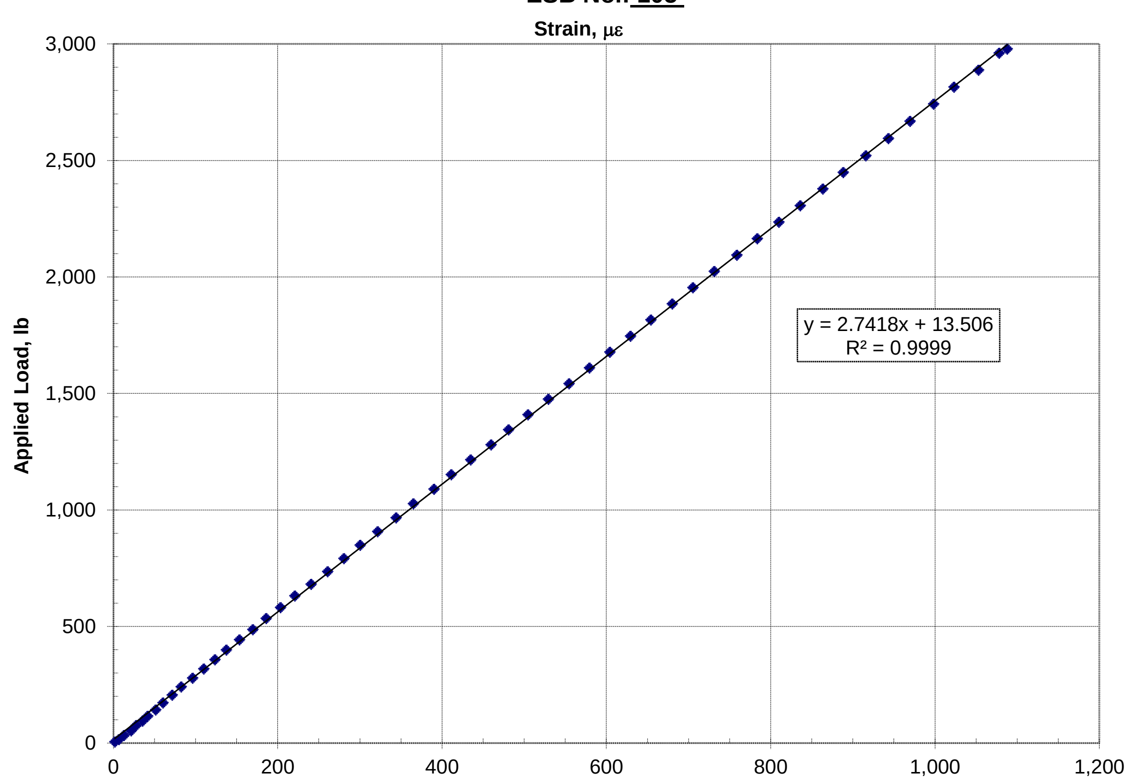
Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck "B 8151-0/PG9" mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, με; R^2 = statistical value, computed for linearity check of measurements

Calibrated By:  Matthew Price

Date: August 16, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 105 ********



Telephone: 512/244-6464 **Fax: 512/244-6067** **lcra@ensoftinc.com**

LYMON C. REESE & ASSOCIATES, INC.

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **107**

Strain Gauge: EA-06-125BZ-350
Gauge Resistance (Ω): 350+/-0.6%
Gauge Excitation: 2,500 mV (DC)
Gauge Factor (@24ºC): 2.115+/-0.5%

Linear Strain Range: +/-2,000με
Linear Temp. Range: -60ºF to +180ºF
Calibration Temp: 24.8ºC
Approx. Steel Bar OD (@Gage): 0.353 in

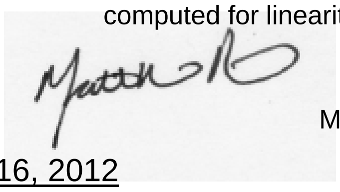
Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 105.3 feet

Connector Details: Turck "BS 8151-0/PG9" Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

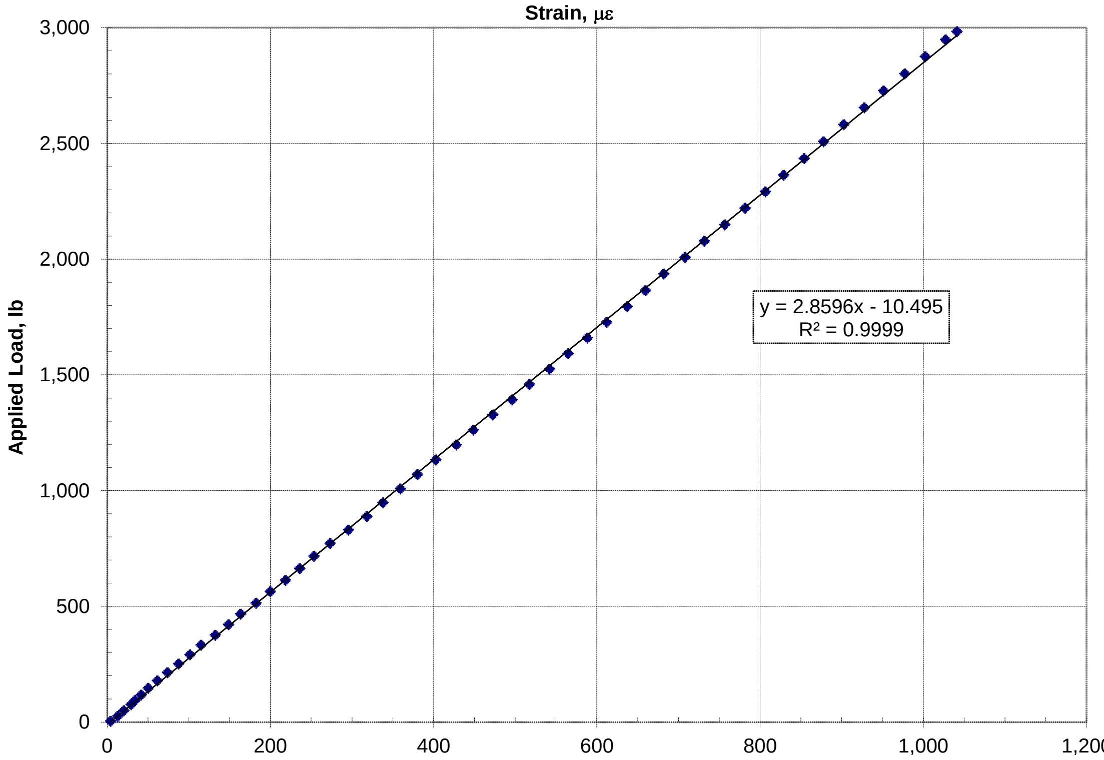
Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck "B 8151-0/PG9" mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, με; R^2 = statistical value, computed for linearity check of measurements

Calibrated By:  Matthew Price

Date: August 16, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 107 ********



Telephone: 512/244-6464 Fax: 512/244-6067 lcra@ensoftinc.com

LYMON C. REESE & ASSOCIATES, INC.

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **109**

Strain Gauge: C2A-06-250LW-350
Gauge Resistance (Ω): 350+/-0.6%
Gauge Excitation: 2,500 mV (DC)
Gauge Factor (@24ºC): 2.105+/-0.5%

Linear Strain Range: +/-2,000με
Linear Temp. Range: -60ºF to +180ºF
Calibration Temp: 24.9ºC
Approx. Steel Bar OD (@Gage): 0.349 in

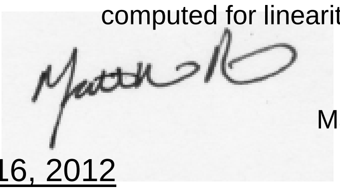
Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 105 feet

Connector Details: Turck "BS 8151-0/PG9" Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

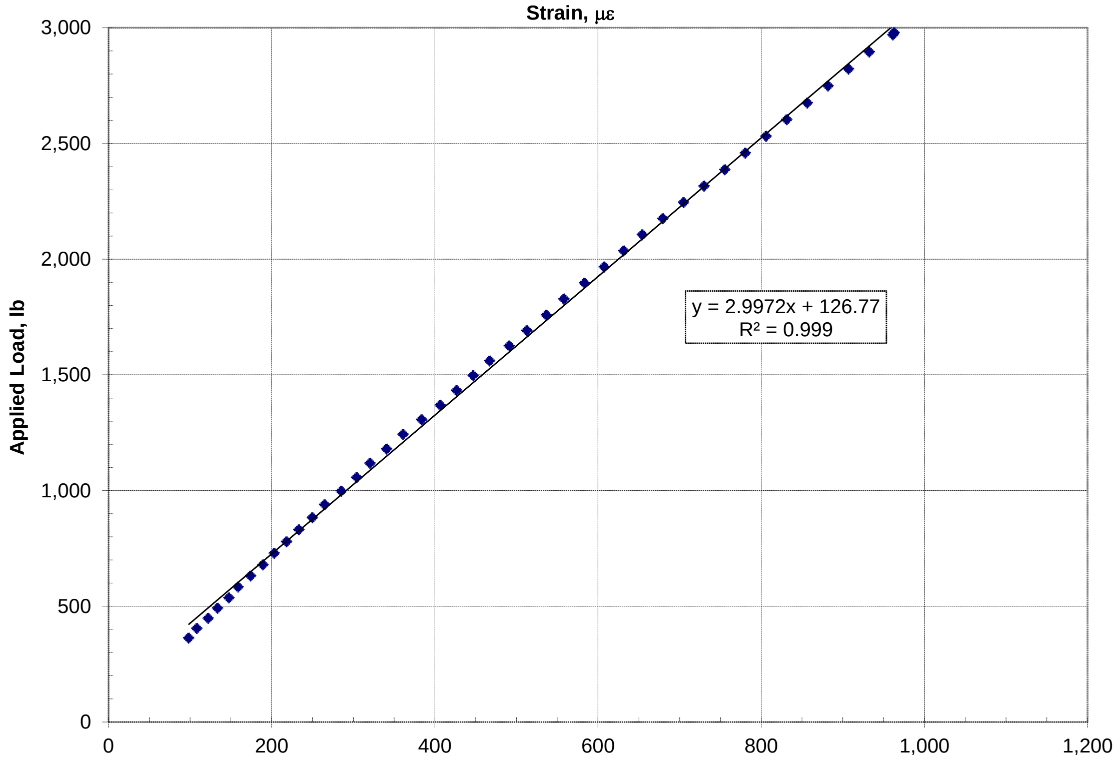
Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck "B 8151-0/PG9" mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, με; R^2 = statistical value, computed for linearity check of measurements

Calibrated By:  Matthew Price

Date: August 16, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 109 ********



Telephone: 512/244-6464 **Fax: 512/244-6067** **lcra@ensoftinc.com**

Instrumentation Used on Test Shaft #2

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Displacement Transducer Calibration Report

Range: 150 mm

Calibration Date: August 15, 2012

Serial Number: 1218853

Temperature: 23.7 °C

Calibration Instruction: CI-4400

Technician:

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2434	2433	2434	-0.26	-0.18	-0.03	-0.02
30.0	3415	3416	3416	30.09	0.06	30.05	0.03
60.0	4390	4388	4389	60.18	0.12	60.01	0.01
90.0	5359	5358	5359	90.15	0.10	89.98	-0.02
120.0	6325	6324	6325	120.01	0.01	119.97	-0.02
150.0	7288	7288	7288	149.79	-0.14	150.02	0.02

(mm) Linear Gage Factor (G): 0.03091 (mm/ digit)

Regression Zero: 2442

Polynomial Gage Factors: A: 7.1789E-08 B: 0.03021 C: ______

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

(inches) Linear Gage Factor (G): 0.001217 (inches/digit)

Polynomial Gage Factors: A: 2.8263E-09 B: 0.001189 C: ______

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

Refer to manual for temperature correction information.

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Displacement Transducer Calibration Report

Range: 150 mm

Calibration Date: August 15, 2012

Serial Number: 1218854

Temperature: 23.7 °C

Calibration Instruction: CI-4400

Technician:

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2374	2371	2373	-0.26	-0.17	-0.01	-0.01
30.0	3364	3362	3363	30.03	0.02	30.00	0.00
60.0	4351	4350	4351	60.23	0.16	60.06	0.04
90.0	5325	5329	5327	90.10	0.07	89.93	-0.05
120.0	6307	6306	6307	120.05	0.04	120.02	0.02
150.0	7278	7277	7278	149.75	-0.17	150.00	0.00

(mm) Linear Gage Factor (G): 0.03058 (mm/ digit)

Regression Zero: 2381

Polynomial Gage Factors: A: 7.3499E-08 B: 0.02987 C: ____________

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

(inches) Linear Gage Factor (G): 0.001204 (inches/digit)

Polynomial Gage Factors: A: 2.8937E-09 B: 0.001176 C: ____________

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

Refer to manual for temperature correction information.

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Displacement Transducer Calibration Report

Range: 150 mm

Calibration Date: August 15, 2012

Serial Number: 1218855

Temperature: 23.7 °C

Calibration Instruction: CI-4400

Technician:

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2351	2351	2351	-0.25	-0.16	-0.01	-0.01
30.0	3337	3335	3336	30.07	0.05	30.01	0.01
60.0	4316	4315	4316	60.22	0.15	60.02	0.01
90.0	5289	5288	5289	90.17	0.11	89.97	-0.02
120.0	6260	6259	6260	120.05	0.04	120.00	0.00
150.0	7226	7224	7225	149.77	-0.15	150.01	0.00

(mm) Linear Gage Factor (G): 0.03078 (mm/ digit)

Regression Zero: 2359

Polynomial Gage Factors: A: 7.6081E-08 B: 0.03005 C: ______

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

(inches) Linear Gage Factor (G): 0.001212 (inches/digit)

Polynomial Gage Factors: A: 2.9953E-09 B: 0.001183 C: ______

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

Refer to manual for temperature correction information.

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Displacement Transducer Calibration Report

Range: 150 mm

Calibration Date: August 15, 2012

Serial Number: 1218856

Temperature: 23.7 °C

Calibration Instruction: CI-4400

Technician:

GK-401 Reading Position B

Actual Displacement (mm)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Displacement (Linear)	Error Linear (%FS)	Calculated Displacement (Polynomial)	Error Polynomial (%FS)
0.0	2392	2390	2391	-0.28	-0.18	-0.01	-0.01
30.0	3379	3378	3379	30.09	0.06	30.02	0.01
60.0	4359	4359	4359	60.24	0.16	60.01	0.01
90.0	5334	5333	5334	90.21	0.14	89.98	-0.02
120.0	6305	6304	6305	120.07	0.04	120.00	0.00
150.0	7270	7269	7270	149.74	-0.17	150.00	0.00

(mm) Linear Gage Factor (G): 0.03075 (mm/ digit)

Regression Zero: 2400

Polynomial Gage Factors: A: 8.6833E-08 B: 0.02991 C: ________

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

(inches) Linear Gage Factor (G): 0.001211 (inches/digit)

Polynomial Gage Factors: A: 3.4186E-09 B: 0.001178 C: ________

Calculate C by setting D = 0 and R_1 = initial field zero reading into the polynomial equation

Calculated Displacement: **Linear, $D = G(R_1 - R_0)$**

Polynomial, $D = AR_1^2 + BR_1 + C$

Refer to manual for temperature correction information.

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

Certificate of Calibration

Instrument: Geokon LVWDT

Model: 4450-3X-100

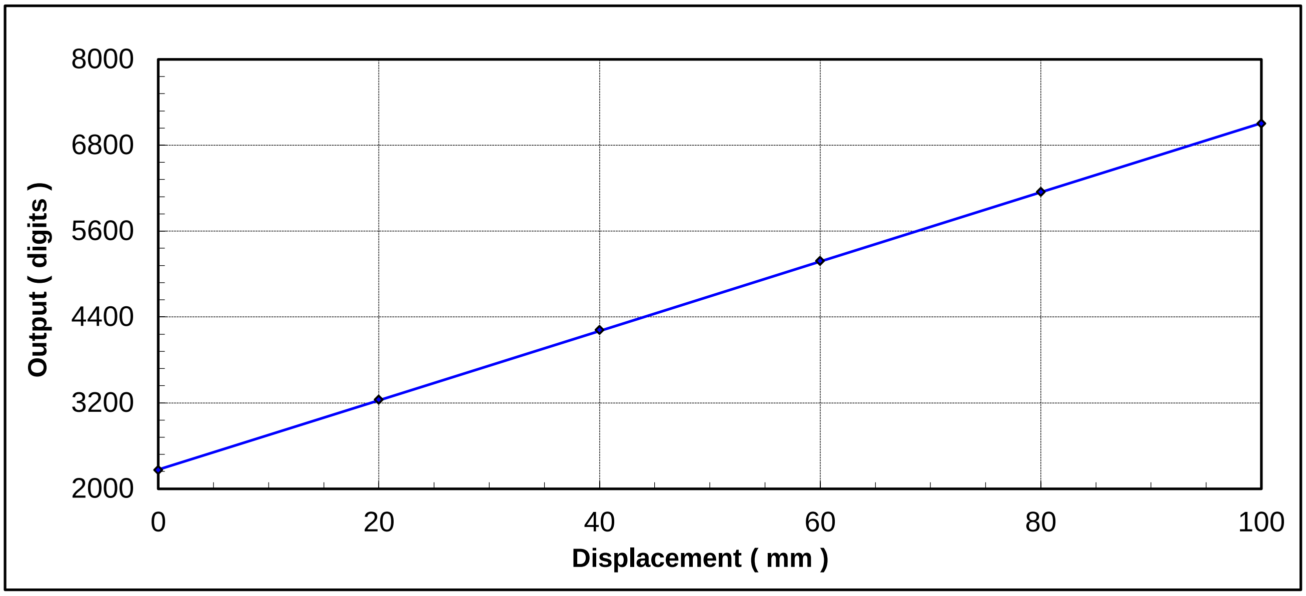
Serial Number: 1124297

Calibration Date: March 12, 2012

Temperature: 23.2 °C

Linear Range: 100 mm

Displacement (mm)	1st Cycle (digits)	2nd Cycle (digits)	Average (digits)	Calculated (mm)	Linearity (% FS)
0	2257	2258	2258	-0.24	-0.24
20	3241	3241	3241	20.08	0.08
40	4215	4214	4215	40.19	0.19
60	5181	5181	5181	60.15	0.15
80	6143	6143	6143	80.02	0.02
100	7100	7101	7101	99.80	-0.20



Linear Gauge Factor: **0.02066** **mm/dig** **0.0008132** **in/dig**

LOADTEST certifies that the above named instrument has been calibrated by comparison with standards traceable to the NIST and was found to be in tolerance in all operating ranges.

Tested by: Michael Crumpton, B.S.C.E. Signed: MZ Crumpton

Approved by: David J. Jakstis, P.E. Signed:

LOADTEST

DEEP FOUNDATION TESTING, EQUIPMENT & SERVICES • SPECIALIZING IN OSTERBERG CELL (O-cell®) TECHNOLOGY
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Certificate of Calibration

Instrument: Geokon LVWDT

Model: 4450-3X-100

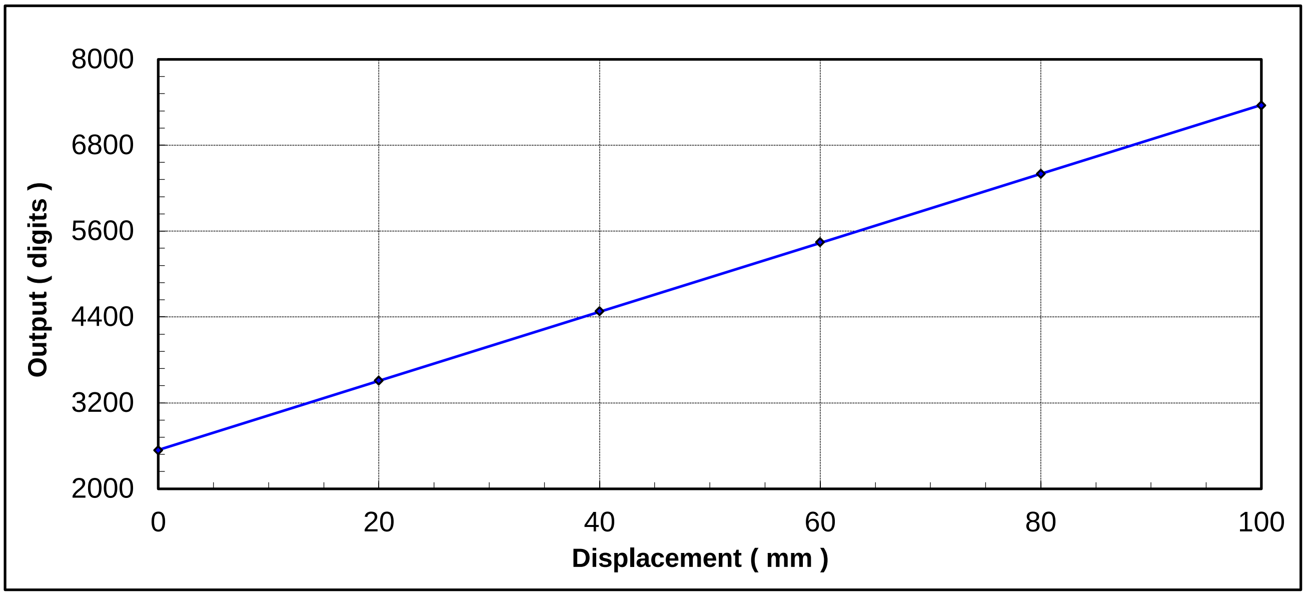
Serial Number: 1124298

Calibration Date: March 12, 2012

Temperature: 23.1 °C

Linear Range: 100 mm

Displacement (mm)	1st Cycle (digits)	2nd Cycle (digits)	Average (digits)	Calculated (mm)	Linearity (% FS)
0	2536	2529	2533	-0.20	-0.20
20	3512	3507	3509	20.06	0.06
40	4481	4476	4479	40.17	0.17
60	5441	5439	5440	60.12	0.12
80	6400	6397	6399	80.01	0.01
100	7355	7354	7354	99.84	-0.16



Linear Gauge Factor: **0.02075** **mm/dig** **0.0008168** **in/dig**

LOADTEST certifies that the above named instrument has been calibrated by comparison with standards traceable to the NIST and was found to be in tolerance in all operating ranges.

Tested by: Michael Crumpton, B.S.C.E. Signed: M Z Crumpton

Approved by: David J. Jakstis, P.E. Signed:

LOADTEST

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Certificate of Calibration

Instrument: Geokon LVWDT

Model: 4450-3X-100

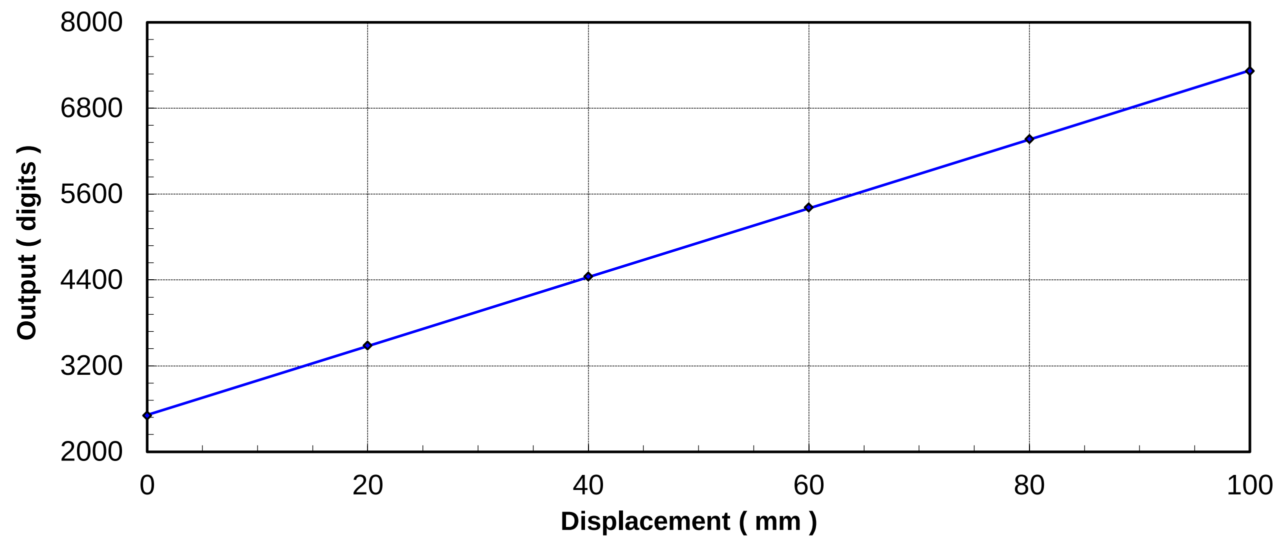
Serial Number: 1124300

Calibration Date: March 12, 2012

Temperature: 21.9 °C

Linear Range: 100 mm

Displacement (mm)	1st Cycle (digits)	2nd Cycle (digits)	Average (digits)	Calculated (mm)	Linearity (% FS)
0	2507	2502	2504	-0.21	-0.21
20	3482	3478	3480	20.06	0.06
40	4450	4445	4447	40.17	0.17
60	5410	5407	5409	60.14	0.14
80	6366	6364	6365	80.02	0.02
100	7320	7316	7318	99.81	-0.19



Linear Gauge Factor: 0.02078 **mm/dig** 0.0008182 **in/dig**

LOADTEST certifies that the above named instrument has been calibrated by comparison with standards traceable to the NIST and was found to be in tolerance in all operating ranges.

Tested by: Michael Crumpton, B.S.C.E. Signed: M Z Crumpton

Approved by: David J. Jakstis, P.E. Signed:

LOADTEST

DEEP FOUNDATION TESTING, EQUIPMENT & SERVICES • SPECIALIZING IN OSTERBERG CELL (O-cell®) TECHNOLOGY
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Certificate of Calibration

Instrument: WIKA Bourdon Gauge

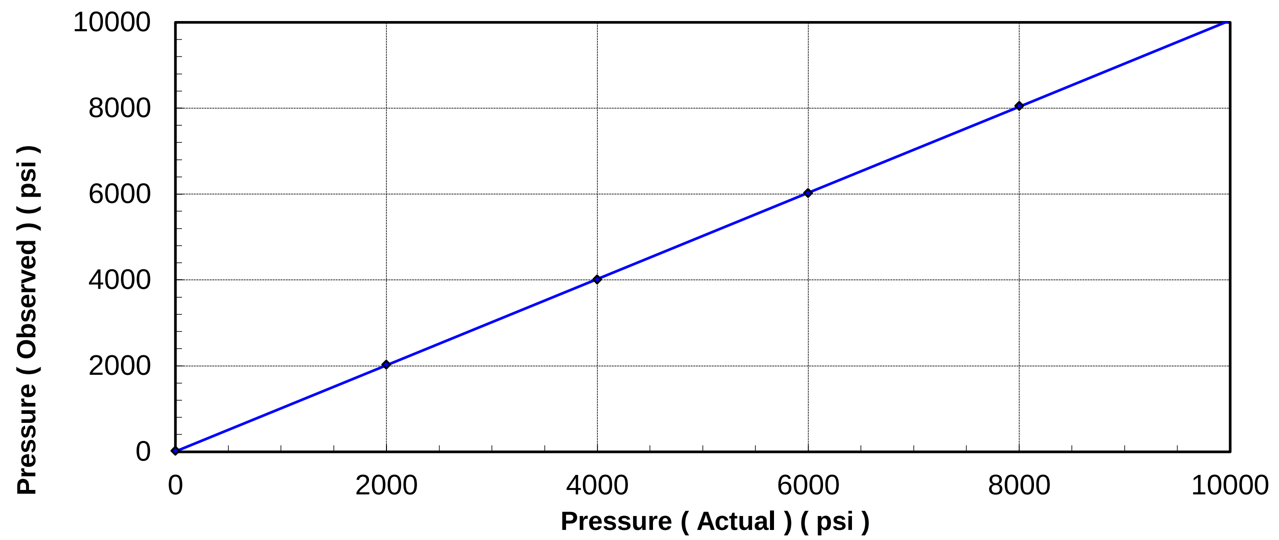
Model: 232.50 - 6"

Serial Number: 2489461

Calibration Date: March 13, 2012

Temperature: 24.7 °C
Pressure: 102.2 kPa
Linear Range: 10000 psi

Pressure (psi)	1st Cycle (psi)	2nd Cycle (psi)	Average (psi)	Calculated (psi)	Linearity (% FS)
0	17	14	16	7	0.07
2000	2016	2027	2022	2006	0.06
4000	4001	4005	4003	3981	-0.19
6000	6022	6022	6022	5993	-0.07
8000	8052	8047	8050	8013	0.13
10000	10042	10045	10044	10000	0.00



Pass/Fail: **PASS**

LOADTEST certifies that the above named instrument has been calibrated by comparison with standards traceable to the NIST and was found to be in tolerance in all operating ranges.

Tested by: Michael Crumpton, B.S.C.E. Signed: M Z Crumpton

Approved by: David J. Jakstis, P.E. Signed:

Certificate of Calibration

Instrument: Geokon VW PX

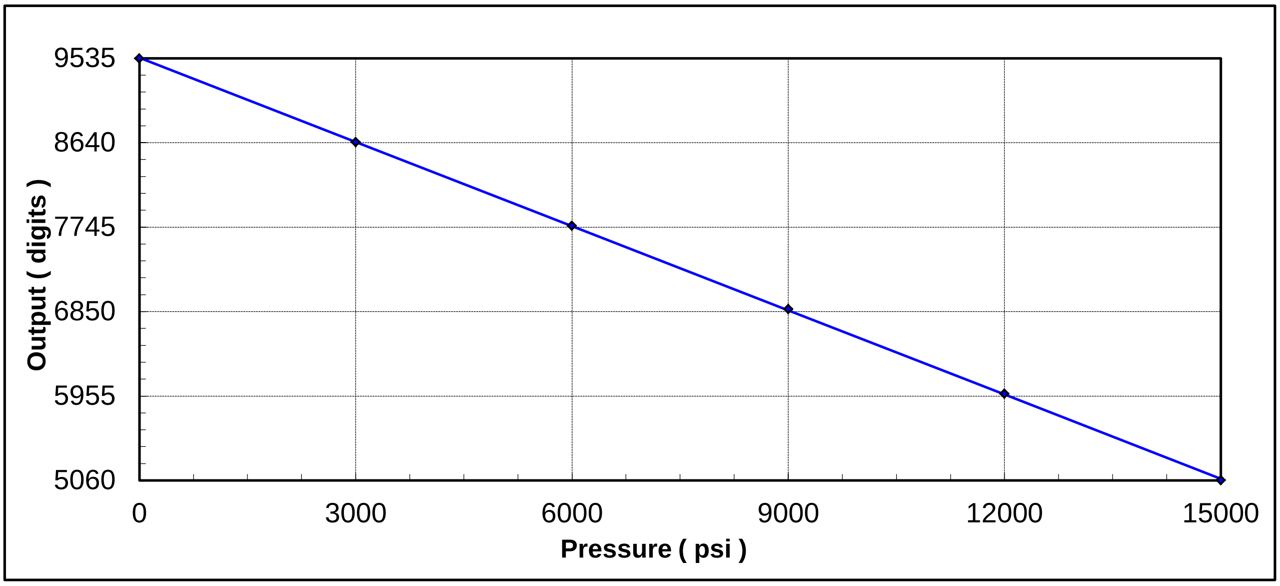
Model: 4500HH-100MPa

Serial Number: 1124389

Calibration Date: March 12, 2012

Temperature: 21.1 °C
Barometric Pressure: 102.2 kPa
Linear Range: 15000 psi

Pressure (psi)	1st Cycle (digits)	2nd Cycle (digits)	Average (digits)	Calculated (psi)	Linearity (% FS)
0	9533	9535	9534	24.48	0.16
3000	8645	8644	8645	3013.54	0.09
6000	7762	7760	7761	5982.44	-0.12
9000	6875	6880	6878	8951.33	-0.32
12000	5972	5986	5979	11970.63	-0.20
15000	5060	5062	5061	15055.46	0.37



Linear Gauge Factor: -3.3604 **psi/dig** -0.0231690 **MPa/dig**

LOADTEST certifies that the above named instrument has been calibrated by comparison with standards traceable to the NIST and was found to be in tolerance in all operating ranges.

Tested by: Michael Crumpton, B.S.C.E. Signed: MZ Crumpton

Approved by: David J. Jakstis, P.E. Signed:

LOADTEST

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LYMON C. REESE & ASSOCIATES, INC.

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **111**

Strain Gauge:	C2A-06-250LW-350	**Linear Strain Range:**	+/-2,000με
Gauge Resistance (Ω):	350+/-0.6%	**Linear Temp. Range:**	-60ºF to +180ºF
Gauge Excitation:	2,500 mV (DC)	**Calibration Temp:**	24.8ºC
Gauge Factor (@24ºC):	2.105+/-0.5%	**Approx. Steel Bar OD (@Gage):**	0.356 in

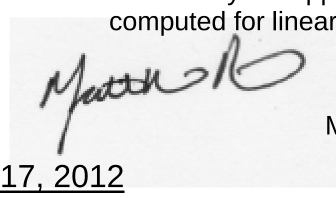
Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 70 feet

Connector Details: Turck "BS 8151-0/PG9" Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

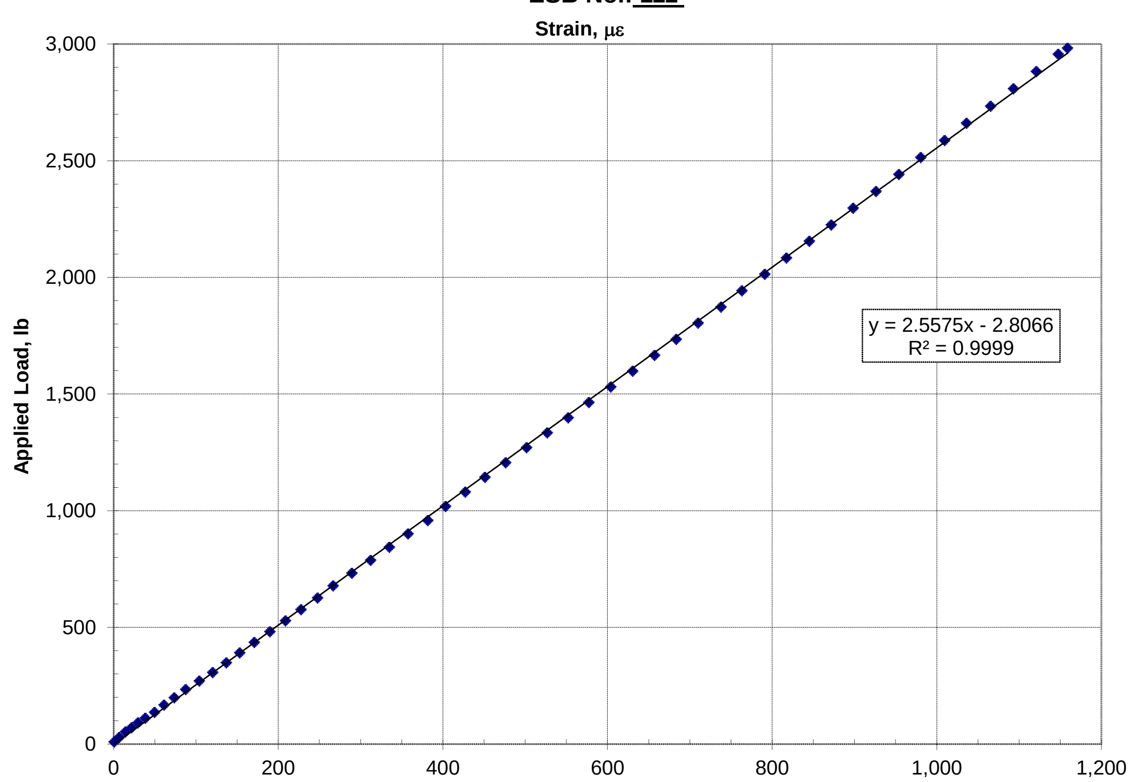
Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck "B 8151-0/PG9" mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, με; R^2 = statistical value, computed for linearity check of measurements

Calibrated By:  Matthew Price

Date: August 17, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 111 ********



Telephone: 512/244-6464 **Fax: 512/244-6067** **lcra@ensoftinc.com**

LYMON C. REESE & ASSOCIATES, INC.

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **112**

Strain Gauge:	C2A-06-250LW-350	**Linear Strain Range:**	+/-2,000με
Gauge Resistance (Ω):	350+/-0.6%	**Linear Temp. Range:**	-60ºF to +180ºF
Gauge Excitation:	2,500 mV (DC)	**Calibration Temp:**	24.8ºC
Gauge Factor (@24ºC):	2.105+/-0.5%	**Approx. Steel Bar OD (@Gage):**	0.353 in

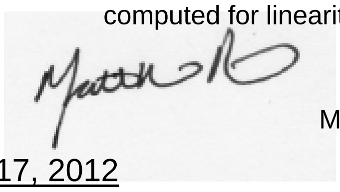
Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 80 feet

Connector Details: Turck "BS 8151-0/PG9" Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

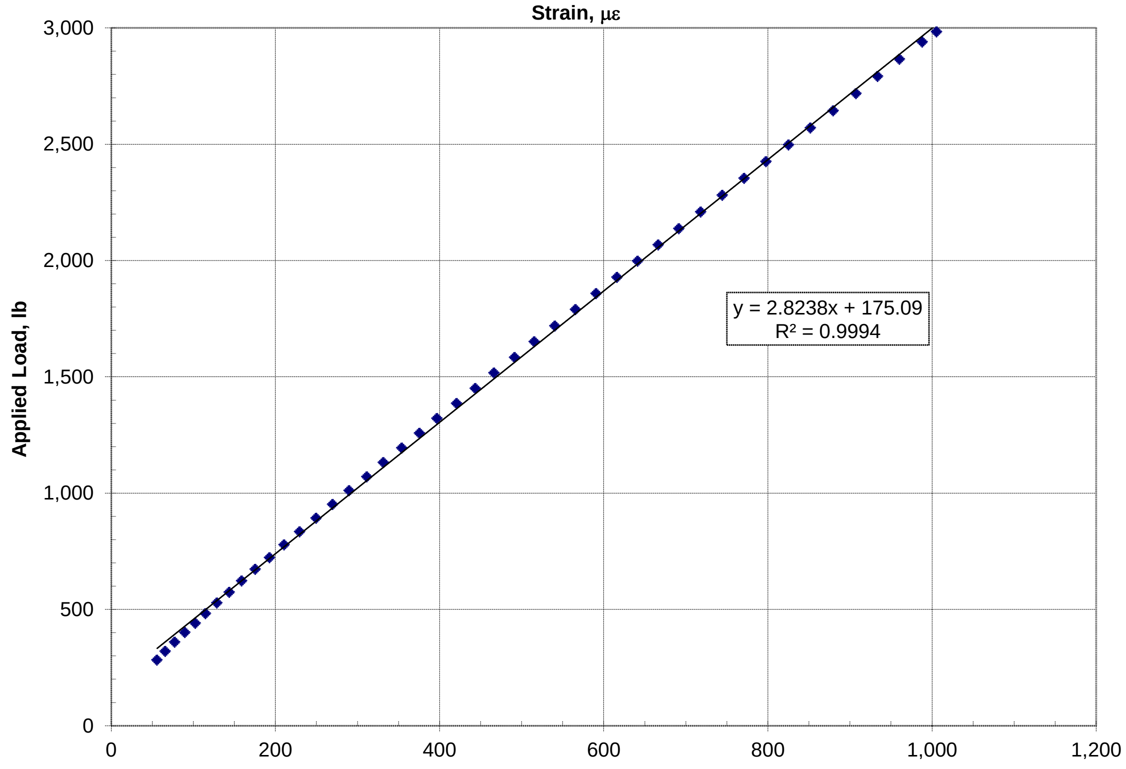
Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck "B 8151-0/PG9" mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, με; R^2 = statistical value, computed for linearity check of measurements

Calibrated By:  Matthew Price

Date: August 17, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 112 ********



Telephone: 512/244-6464 **Fax: 512/244-6067** **lcra@ensoftinc.com**

LYMON C. REESE & ASSOCIATES, INC.

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **114**

Strain Gauge:	C2A-06-250LW-350	**Linear Strain Range:**	+/-2,000με
Gauge Resistance (Ω):	350+/-0.6%	**Linear Temp. Range:**	-60ºF to +180ºF
Gauge Excitation:	2,500 mV (DC)	**Calibration Temp:**	24.5ºC
Gauge Factor (@24ºC):	2.105+/-0.5%	**Approx. Steel Bar OD (@Gage):**	0.351 in

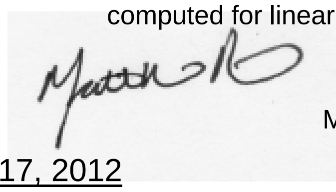
Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 90 feet

Connector Details: Turck "BS 8151-0/PG9" Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck "B 8151-0/PG9" mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

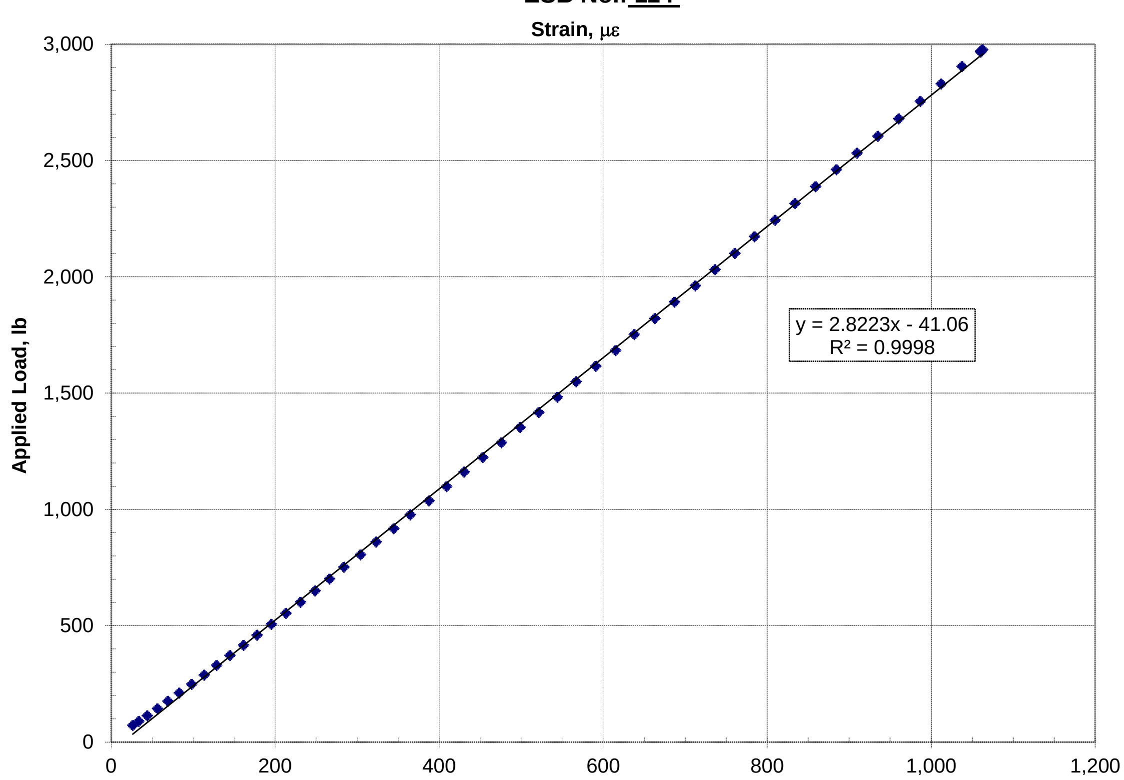
Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, με; R^2 = statistical value, computed for linearity check of measurements



Calibrated By: Matthew Price

Date: August 17, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 114 ********



Telephone: 512/244-6464 **Fax: 512/244-6067** **lcra@ensoftinc.com**

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **201**

Strain Gauge: C2A-06-250LW-350
Gauge Resistance (Ω): 350+/-0.6%
Gauge Excitation: 2,500 mV (DC)
Gauge Factor (@24ºC): 2.105+/-0.5%

Linear Strain Range: +/-2,000με
Linear Temp. Range: -60ºF to +180ºF
Calibration Temp: 25.1ºC
Approx. Steel Bar OD (@Gage): 0.358 in

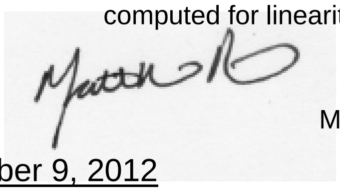
Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 98.7 feet

Connector Details: Turck "BS 8151-0/PG9" Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck "B 8151-0/PG9" mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

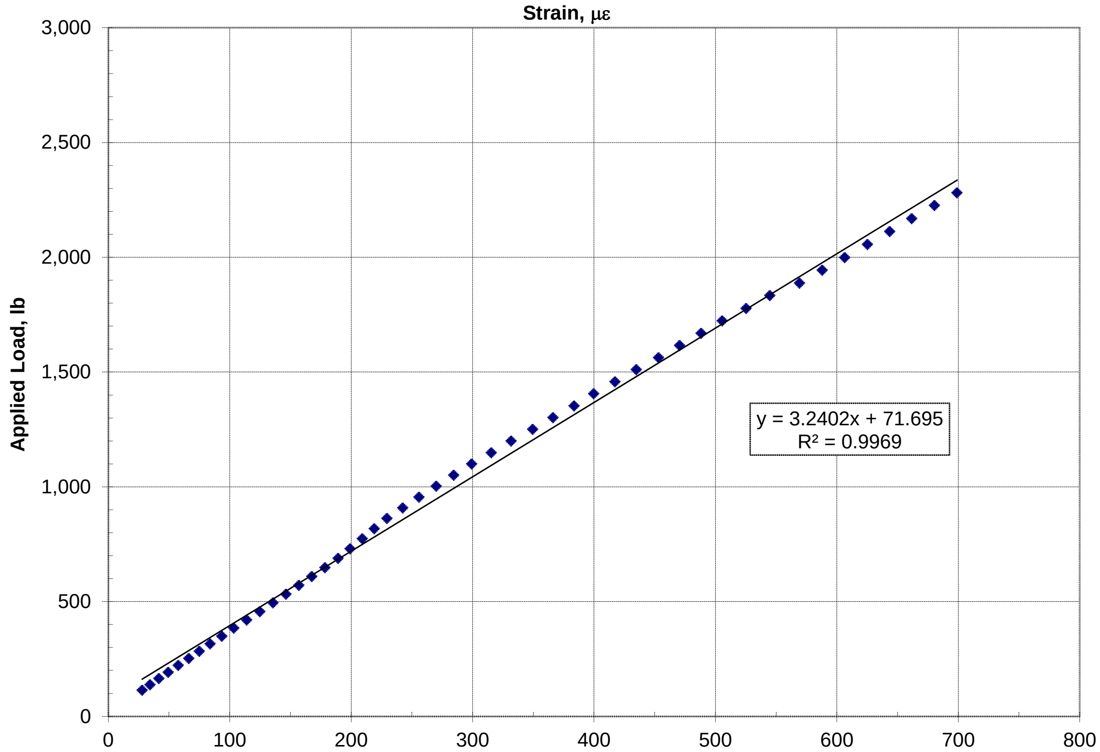
Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, με; R^2 = statistical value, computed for linearity check of measurements



Calibrated By: Matthew Price

Date: September 9, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 201 ********



Telephone: 512/244-6464 Fax: 512/244-6067 lcra@ensoftinc.com

LYMON C. REESE & ASSOCIATES, INC.

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **203**

Strain Gauge: C2A-06-250LW-350
Gauge Resistance (Ω): 350+/-0.6%
Gauge Excitation: 2,500 mV (DC)
Gauge Factor (@24ºC): 2.105+/-0.5%

Linear Strain Range: +/-2,000με
Linear Temp. Range: -60ºF to +180ºF
Calibration Temp: 25.1ºC
Approx. Steel Bar OD (@Gage): 0.357 in

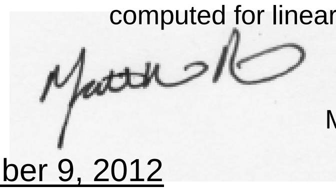
Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 99.7 feet

Connector Details: Turck "BS 8151-0/PG9" Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

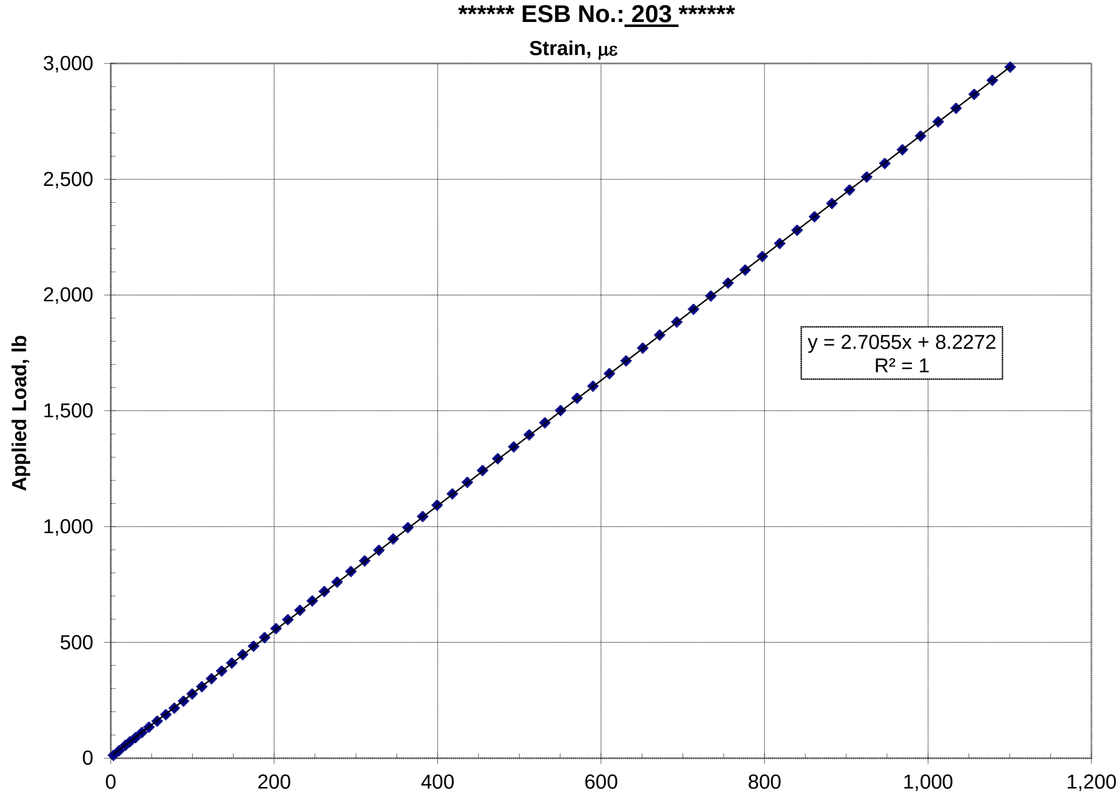
Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck "B 8151-0/PG9" mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, με; R^2 = statistical value, computed for linearity check of measurements

Calibrated By:  Matthew Price

Date: September 9, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 203 ********



Telephone: 512/244-6464 **Fax: 512/244-6067** **lcra@ensoftinc.com**

LYMON C. REESE & ASSOCIATES, INC.

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **204**

Strain Gauge:	C2A-06-250LW-350	**Linear Strain Range:**	+/-2,000με
Gauge Resistance (Ω):	350+/-0.6%	**Linear Temp. Range:**	-60ºF to +180ºF
Gauge Excitation:	2,500 mV (DC)	**Calibration Temp:**	25.1ºC
Gauge Factor (@24ºC):	2.105+/-0.5%	**Approx. Steel Bar OD (@Gage):**	0.357 in

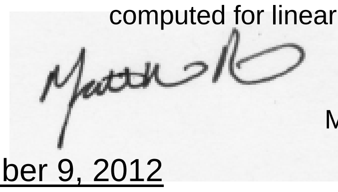
Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 98.1 feet

Connector Details: Turck "BS 8151-0/PG9" Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

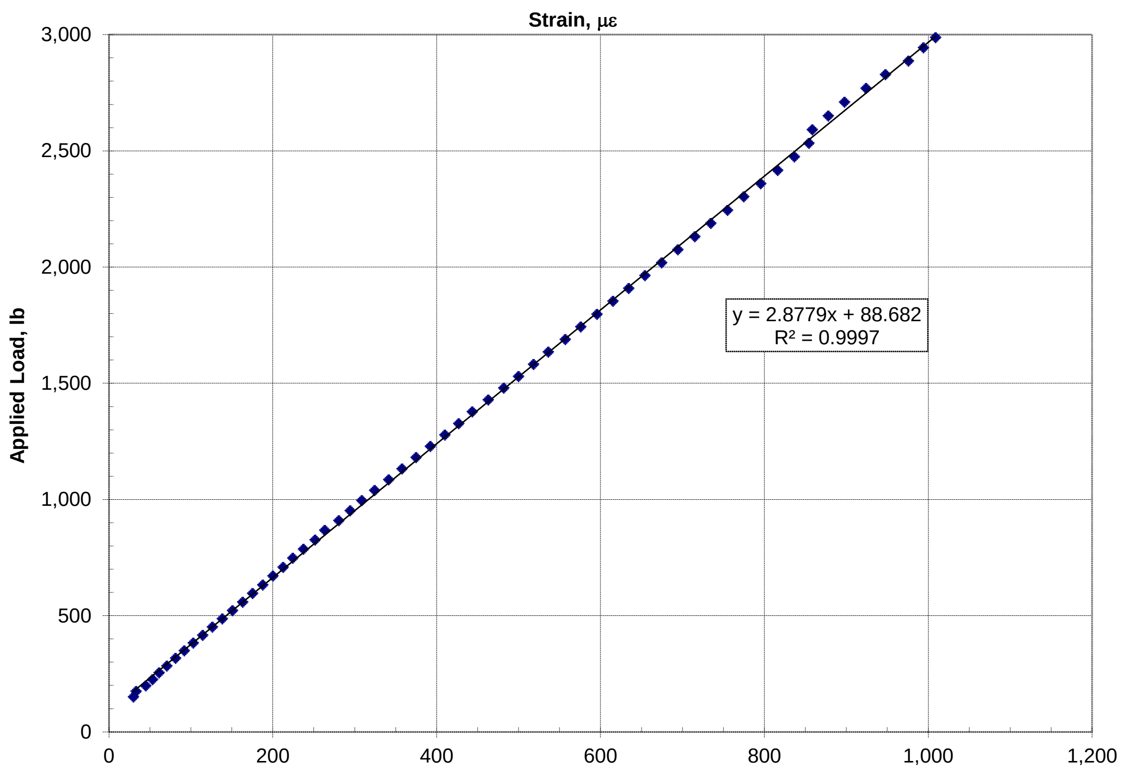
Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck "B 8151-0/PG9" mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, με; R^2 = statistical value, computed for linearity check of measurements

Calibrated By:  Matthew Price

Date: September 9, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 204 ********



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LYMON C. REESE & ASSOCIATES, INC.

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **205**

Strain Gauge:	C2A-06-250LW-350	**Linear Strain Range:**	+/-2,000με
Gauge Resistance (Ω):	350+/-0.6%	**Linear Temp. Range:**	-60ºF to +180ºF
Gauge Excitation:	2,500 mV (DC)	**Calibration Temp:**	25.1ºC
Gauge Factor (@24ºC):	2.105+/-0.5%	**Approx. Steel Bar OD (@Gage):**	0.348 in

Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 98.8 feet

Connector Details: Turck "BS 8151-0/PG9" Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

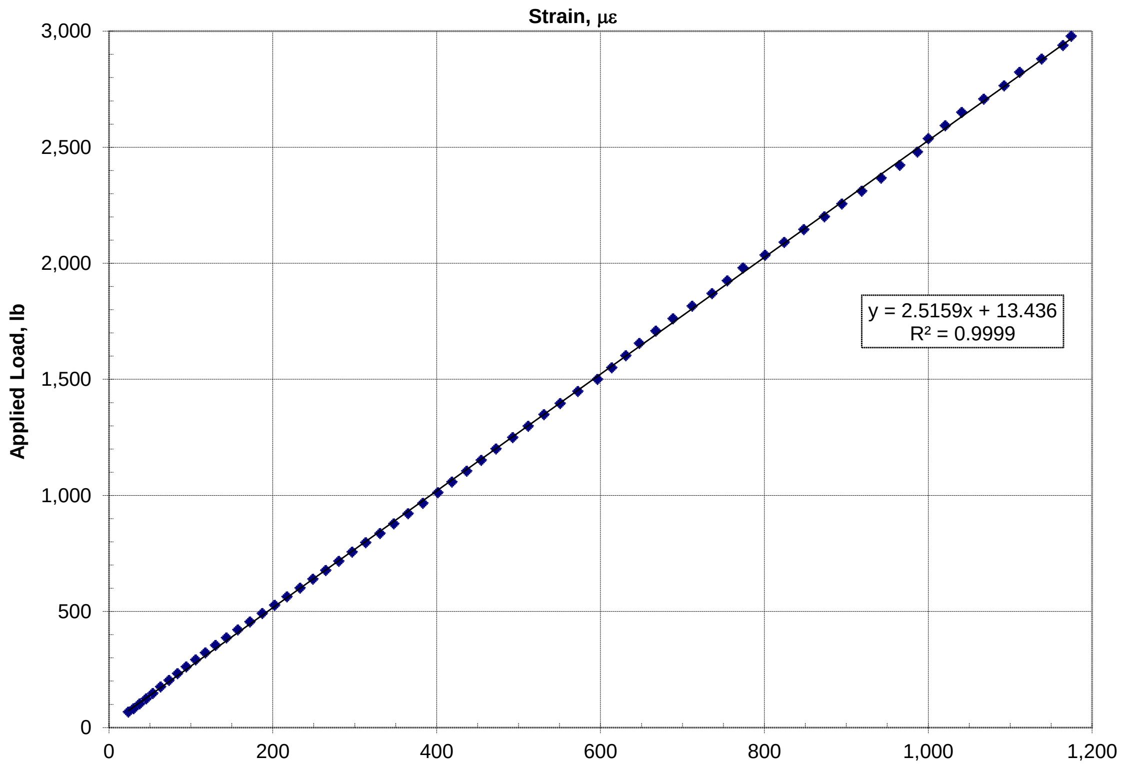
Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck "B 8151-0/PG9" mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, με; R^2 = statistical value, computed for linearity check of measurements

Calibrated By: Matthew Price

Date: September 9, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 205 ********



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LYMON C. REESE & ASSOCIATES, INC.

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **206**

Strain Gauge:	C2A-06-250LW-350	**Linear Strain Range:**	+/-2,000$\mu\varepsilon$
Gauge Resistance (Ω):	350+/-0.6%	**Linear Temp. Range:**	-60ºF to +180ºF
Gauge Excitation:	2,500 mV (DC)	**Calibration Temp:**	25.1ºC
Gauge Factor (@24ºC):	2.105+/-0.5%	**Approx. Steel Bar OD (@Gage):**	0.332 in

Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 99.7 feet

Connector Details: Turck "BS 8151-0/PG9" Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

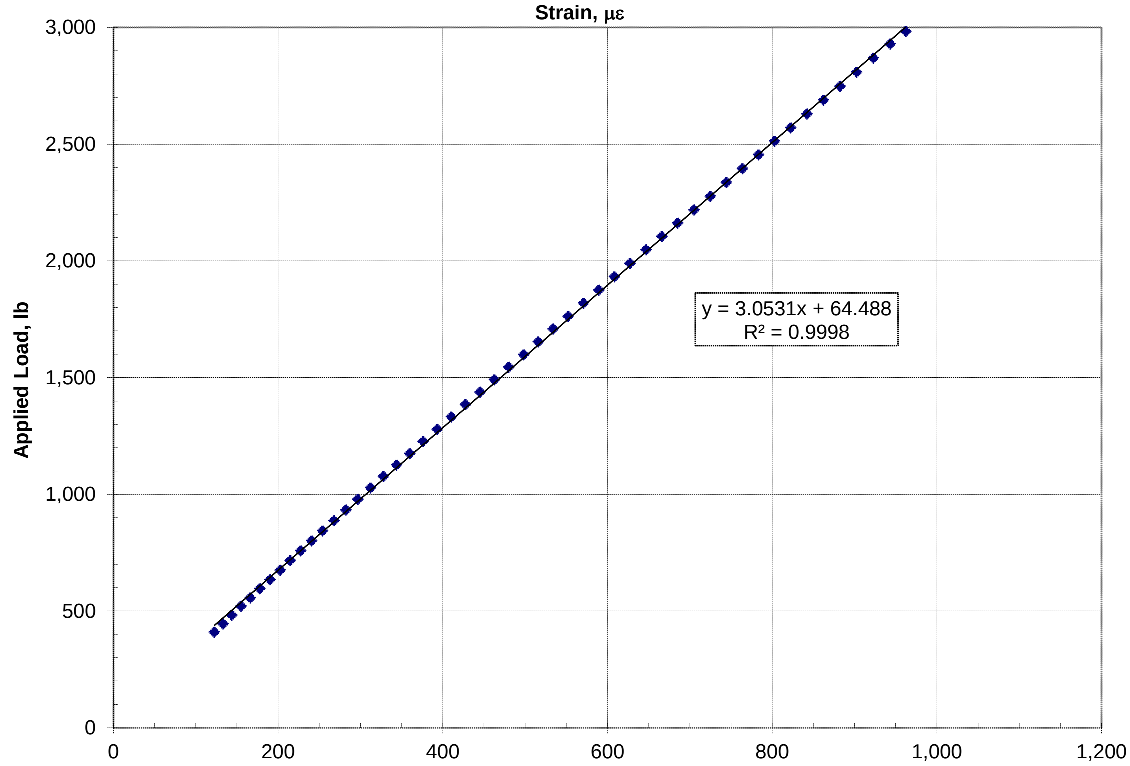
Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck "B 8151-0/PG9" mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, $\mu\varepsilon$; R^2 = statistical value, computed for linearity check of measurements

Calibrated By: Matthew Price

Date: September 9, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 206 ********



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LYMON C. REESE & ASSOCIATES, INC.

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **207**

Strain Gauge: C2A-06-250LW-350
Gauge Resistance (Ω): 350+/-0.6%
Gauge Excitation: 2,500 mV (DC)
Gauge Factor (@24ºC): 2.105+/-0.5%

Linear Strain Range: +/-2,000με
Linear Temp. Range: -60ºF to +180ºF
Calibration Temp: 25.0ºC
Approx. Steel Bar OD (@Gage): 0.350 in

Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 98.2 feet

Connector Details: Turck "BS 8151-0/PG9" Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

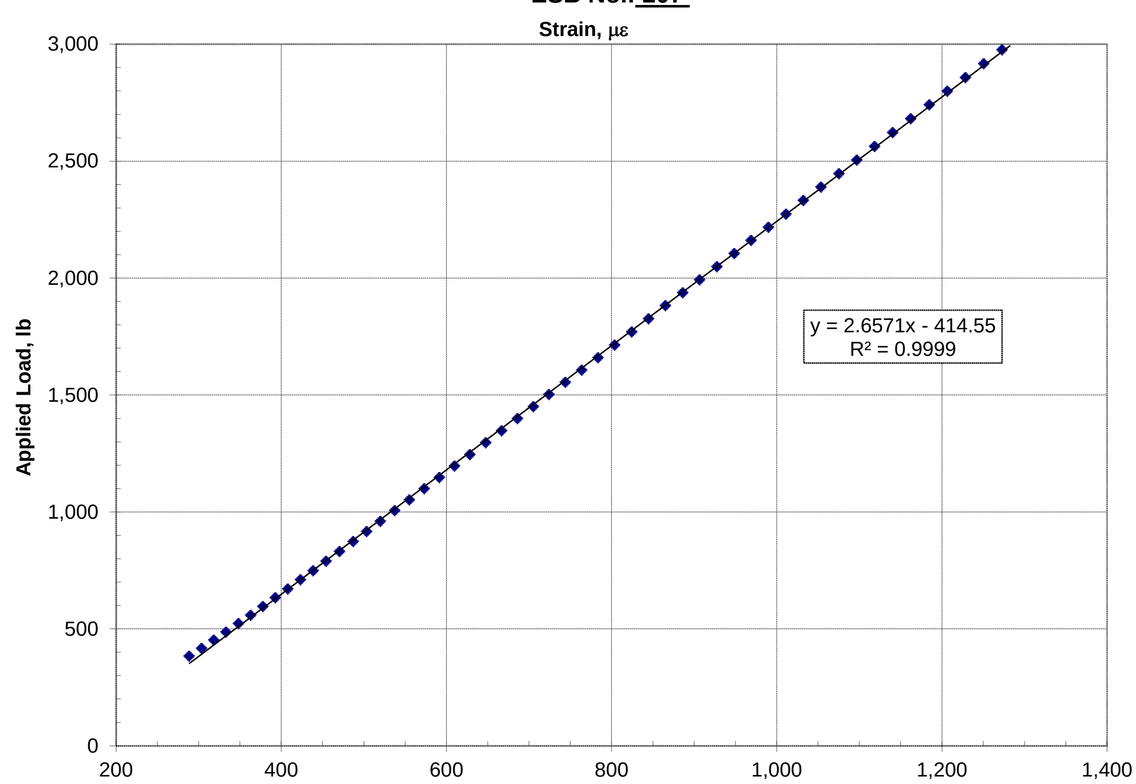
Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck "B 8151-0/PG9" mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, με; R^2 = statistical value, computed for linearity check of measurements

Calibrated By: Matthew Price

Date: September 9, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 207 ********



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LYMON C. REESE & ASSOCIATES, INC.

ELECTRICAL STRAIN BAR LINEARITY RECORD

Model: ESB
Serial Number: **209**

Strain Gauge:	C2A-06-250LW-350	**Linear Strain Range:**	+/-2,000$\mu\varepsilon$
Gauge Resistance (Ω):	350+/-0.6%	**Linear Temp. Range:**	-60ºF to +180ºF
Gauge Excitation:	2,500 mV (DC)	**Calibration Temp:**	25.0ºC
Gauge Factor (@24ºC):	2.105+/-0.5%	**Approx. Steel Bar OD (@Gage):**	0.357 in

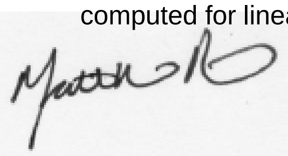
Cable Type: Belden 9939 (AWG22, 3 conductors, white & black connected to one leadwire on strain gauge while red connected to other leadwire)

Cable Length: 101.1 feet

Connector Details: Turck "BS 8151-0/PG9" Male Connector. Wire conductors assembled as follows: Red conductor to Position #1, White conductor to #2 and Black conductor to #3.

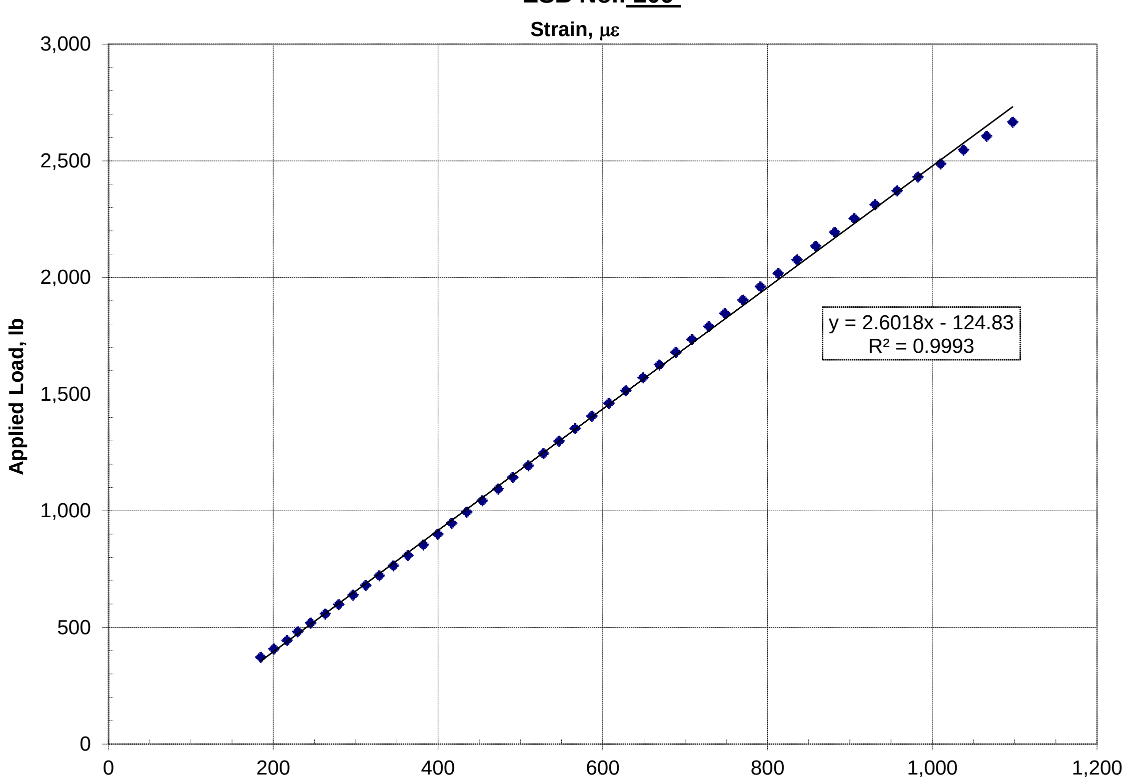
Wiring Details: Use Quarter Bridge Wheatstone completion circuit with 350 Ω precision resistors, wiring must be as follows (short lengths of cables wired to Turck "B 8151-0/PG9" mating receptacles can be provided on order): Position #1 (Red) to Signal (+),#2 (White) to Signal (-) and #3 (Black) to Shield

Linearity Formula: *(indicated in graph below)*
Where: y = Applied Load, lbs; x = strain, $\mu\varepsilon$; R^2 = statistical value, computed for linearity check of measurements

Calibrated By:  Matthew Price

Date: September 9, 2012

ELECTRICAL STRAIN BAR LINEARITY CHART
******** ESB No.: 209 ********



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ASTM D2113 "Standard Practice for Rock Core Drilling and Sampling of Rock for Site Investigation"

ASTM D2166 "Standard Test Method for Unconfined Compressive Strength of Cohesive Soil"

ASTM D2216 "Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass"

ASTM D4318 "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils"

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